
Ex-libris
Charles Atwood
Kofoid
BMC

LIBRARY OF · INSPIRATION · AND · ACHIEVEMENT ·

EDWARD EVERETT HALE
· EDITOR · IN · CHIEF ·

MALCOLM

WATT DISCOVERING THE POWER OF STEAM

LIBRARY
OF INSPIRATION
AND
ACHIEVEMENT

MEN OF ACHIEVEMENT: INVENTORS AND SCIENTISTS

WITH AN INTRODUCTION
BY
ALFRED RUSSEL WALLACE

THE
UNIVERSITY SOCIETY
28 FIFTH AVENUE
NEW YORK

WATT DISCOVERING THE POWER OF STEAM

LIBRARY OF INSPIRATION AND ACHIEVEMENT

MEN OF ACHIEVEMENT:- INVENTORS AND SCIENTISTS

WITH AN INTRODUCTION BY

ALFRED RUSSEL WALLACE

THE UNIVERSITY SOCIETY
78 FIFTH AVENUE
NEW YORK

MALCOLM NY

1902

PARTIAL LIST OF SPECIAL CONTRIBUTORS:

Hon. Theodore Roosevelt, President of the United States.
Hon. Grover Cleveland, Ex-President of the United States.
Hon. George F. Hoar, Senator from Massachusetts.
David Starr Jordan, Ex-President Leland Stanford, Jr., University.
Hon. Justin McCarthy, Ex-Member of Parliament.
Gen. Joseph Wheeler, United States Army.
Admiral Robley D. Evans, United States Navy.
William R. Harper, President Chicago University.
James J. Hill, President Great Northern Railroad.
H. H. Vreeland, President Metropolitan Street Railway.
Hon. Seth Low, Mayor of New York.
The Earl of Dunraven, Author of "The Great Divide," "The Upper Yellowstone," etc.
Camille Prevost, French Athletic Expert.
Ray Stannard Baker, Author and Journalist.
Margaret E. Sangster, Author of "The Art of Home-Making."
Herbert Welsh, Editor of "City and State."
William Blaikie, Author of "How to Get Strong and How to Stay So."
Nicholas Murray Butler, President Columbia University.
James B. Angell, President University of Michigan.
Andrew Lang, Author.
Jacob A. Riis, Author and Journalist.
Robert C. Ogden, Partner of John Wanamaker.
George G. Williams, President Chemical National Bank.
H. N. Higinbotham, Marshall Field & Co.
Sir Thomas Lipton, London, England.
Dr. George F. Shrady, Physician, New York.
Rev. Newell Dwight Hillis, Pastor Plymouth Church.
Walter Camp, Author "College Sports," etc.
Sarah K. Bolton, Biographical Writer.
And more than two hundred other well-known writers and successful business men.

INTRODUCTION

By ALFRED RUSSEL WALLACE

A COMPREHENSIVE review of the practical discoveries and striking generalizations of science which have in so many respects changed the outward forms of our civilization, places us in a position to sum up the achievements of the nineteenth century and compare them with what has gone before.

Taking first those inventions and practical applications of science which are perfectly new departures, and which have also so rapidly developed as to have profoundly affected many of our habits, and even our thoughts and our language, we find them to be thirteen in number.

1. Railways, which have revolutionized land travel and the distribution of commodities.

2. Steam navigation, which has done the same thing for ocean travel, and has besides led to the entire reconstruction of the navies of the world.

3. Electric telegraphs, which have produced an even greater revolution in the communication of thought.

4. The telephone, which transmits, or rather reproduces, the voice of the speaker at a distance.

5. Friction matches, which have revolutionized the modes of obtaining fire.

6. Gas lighting, which enormously improved outdoor and other illumination.

7. Electric lighting, another advance, now threatening to supersede gas.

8. Photography, an art which is to the external forms of nature what printing is to thought.

9. The phonograph, which preserves and reproduces sounds as photography preserves and reproduces forms.

10. The Röntgen rays, which render many opaque objects transparent, and open up a new world to photography.

11. Spectrum analysis, which so greatly extends our knowledge of the universe that by its assistance we are able to ascertain the relative heat and chemical constitution of the stars, and ascertain the existence, and measure the rate of motion, of stellar bodies which are entirely invisible.

12. The use of anæsthetics, rendering the most severe surgical operations painless.

13. The use of antiseptics in surgical operations, which has still further extended the means of saving life.

Now, if we ask what inventions comparable with these were made during the previous (eighteenth) century, it seems at first doubtful whether there were any. But we may perhaps admit the development of the steam engine from the rude but still useful machine of Newcomen to the powerful and economical engines of Boulton and Watt. The principle, however, was known long before, and had been practically applied in the previous century by the Marquis of Worcester and by Savery; and the improvements made by Watt, though very important, had a very limited result. The engines made were almost wholly used in pumping the water out of deep mines, and the bulk of the population knew no more of them, nor derived any more direct benefit from them, than if they had not existed.

In the seventeenth century, the one great and far-reaching invention was that of the telescope, which, in its immediate results of extending our knowledge of the universe and giving possibilities of future knowledge not yet exhausted, may rank with spectrum analysis in our own era. The barometer and thermometer are minor discoveries.

In the sixteenth century we have no invention of the first rank, but in the fifteenth we have printing.

The mariner's compass was invented early in the fourteenth century, and was of great importance in rendering ocean navigation possible and thus facilitating the discovery of America.

Then, backward to the dawn of history, or rather to prehistoric times, we have the two great engines of knowledge and discovery—the Indian or Arabic numerals leading to arithmetic and algebra, and, more remote still, the invention of alphabetical writing.

Summing these up, we find only five inventions of the first rank in all preceding time—the telescope, the printing press, the mariner's compass, Arabic numerals, and alphabetical writing, to which we may add the steam engine and the barometer, making seven in all, as against thirteen in our single century.

Coming now to the theoretical discoveries of our time, which have extended our knowledge or widened our conceptions of the universe, we find them to be about equal in number, as follows:

1. The determination of the mechanical equivalent of heat, leading to the great principle of the conservation of energy.

2. The molecular theory of gases.

3. The mode of direct measurement of the velocity of Light, and the experimental proof of the earth's rotation. These are put together, because hardly sufficient alone.

4. The discovery of the function of dust in nature.

5. The theory of definite and multiple proportions in chemistry.

6. The nature of meteors and comets, leading to the meteoritic theory of the universe.

7. The proof of the glacial epoch, its vast extent, and its effects upon the earth's surface.

8. The proof of the great antiquity of man.

9. The establishment of the theory of organic evolution.

10. The cell theory and the recapitulation theory in embryology.

11. The germ theory of the zymotic diseases.

12. The discovery of the nature and function of the white blood corpuscles.

Turning to the past, in the eighteenth century we may perhaps claim two groups of discoveries:

1. The foundation of modern chemistry by Black, Cavendish, Priestley, and Lavoisier; and

2. The foundation of electrical science by Franklin, Galvani, and Volta.

The seventeenth century is richer in epoch-making discoveries, since we have

3. The theory of gravitation established.

4. The discovery of Kepler's laws.

5. The invention of fluxions and the differential calculus.

6. Harvey's proof of the circulation of the blood.

7. Roemer's proof of finite velocity of light by Jupiter's satellites.

Then, going backward, we can find nothing of the first rank except Euclid's wonderful system of geometry, derived from earlier Greek and Egyptian sources, and perhaps the most remarkable mental product of the earliest civilizations; to which we may add the introduction of Arabic numerals, and the use of the alphabet. Thus in all past history we find only eight theories or principles antecedent to the nineteenth century as compared with twelve during that century. It will be well now to give comparative lists of the great inventions and discoveries of the two eras, adding a few others to those above enumerated.

Of the Nineteenth Century.	Of All Preceding Ages.
1. Railways.	1. The mariner's compass.
2. Steamships.	2. The steam engine.
3. Electric telegraphs.	3. The telescope.
4. The telephone.	4. The barometer and thermometer.
5. Lucifer matches.	5. Printing.
6. Gas illumination.	6. Arabic numerals.
7. Electric lighting.	7. Alphabetical writing.
8. Photography.	8. Modern chemistry founded.
9. The phonograph.	9. Electric science founded.
10. The Röntgen rays.	10. Gravitation established.
11. Spectrum analysis.	11. Kepler's laws.
12. Anæsthetics.	
13. Antiseptic surgery.	

14. Conservation of energy.
15. Molecular theory of gases.
16. Velocity of light directly measured, and earth's rotation experimentally shown.
17. The uses of dust.
18. Chemistry, definite proportions.
19. Meteors and the meteoritic theory.
20. The glacial epoch.
21. The antiquity of man.
22. Organic evolution established.
23. Cell theory and embryology.
24. Germ theory of disease, and the function of the leucocytes.

12. The differential calculus.
13. The circulation of the blood.
14. Light proved to have finite velocity.
15. The development of geometry.

Of course these numbers are not absolute. Either series may be increased or diminished by taking account of other discoveries as of equal importance, or by striking out some which may be considered as below the grade of an important or epoch-making step in science or civilization. But the difference between the two lists is so large that probably no competent judge would bring them to an equality. Again, it is noteworthy that nothing like a regular gradation is perceptible during the last three or four centuries. The eighteenth century, instead of showing some approximation to the wealth of discovery in our own age, is less remarkable than the seventeenth, having only about half the number of really great advances.

It appears then that the statement made by me elsewhere, that for adequate comparison with the nineteenth century we must take, not any preceding century or group of centuries, but rather the whole preceding epoch of human history, is justified, and more than justified, by the comparative lists now

given. And if we take into consideration the change effected in science, in the arts, in all the possibilities of human intercourse, and in the extension of our knowledge, both of our earth and of the whole visible universe, the difference shown by the mere numbers of these advances will have to be considerably increased on account of the marvelous character and vast possibilities of further development of many of our recent discoveries.

Alfred R. Wallace

NOTE BY EDITOR

From a summary of nineteenth-century progress by Professor Ludwig Büchner, of Germany, we take the following passages, which supplement Professor Wallace's statements:

"The improved telescopes of the present time have provided us with such an intimate knowledge of the constitution of the surface of our moon that it is now better known than some parts of the surface of the earth—as in the interior of the great continents of Africa, Australia, and America. Similar information, though to be taken with reserve, was obtained from the remarkable phenomena observed on the surface of the planet Mars. The interpretation of these features has not been thus far absolutely settled, but in the opinion of eminent astronomers they indicate the presence on that planet of thinking beings. [Further reference to this subject will be found in the section on Astronomy.] To the nineteenth century also belongs the somewhat older discovery of the planet Neptune, which was made in such a wonderful way by Leverrier and Galle in 1846. This discovery must be regarded as one of the greatest triumphs of astronomical science, since it was the fruit of a demonstration by mathematical calculations of the existence of a heavenly body, while the actual finding and identification of it were achieved afterward by means of the telescope.

The nineteenth century witnessed the union of electric force with chemistry and technics in the form of electro-chemistry and electro-technics, which open the brightest vistas into the future. For the wonderful force of electricity excels in readiness of application and utility all other forces of nature, and beyond any other vanquishes the checking barriers of space and time. It can, without any special means, be almost directly derived from or changed into all other forms of natural force, and proceeds with an extraordinary velocity through the prescribed paths of the conducting wires. It can, therefore, at any moment be conducted to any place where its effect is required. Dwellings are now illuminated by electricity almost everywhere, and if heating by the same agent and the cooking of food by means of it become common, then is foreshadowed an almost paradisiacal state, in place of the conditions of existence now prevailing with their attendant trouble, uncleanliness, dust, vexation, and disease. And should electro-technics succeed—as there is well-founded hope that it will—in solving the problem of obtaining electricity direct from the fuel, instead of by an expensive indirect method as heretofore, the far-reaching effect of such success can scarcely be overestimated. As with respect to material progress the past century is fittingly called the century of steam, so most likely the twentieth will have to be designated the century of electricity, when the more extended control of the forces of nature by the human mind shall have taken an immense stride in the forward direction. If we add to all this that the grand material as well as intellectual development of the great land of liberty in the far West of our globe, the like of which has never been seen before, promises to continue in the same or even a higher degree, then the men of the new century will of necessity be more profoundly impressed than the children of the present by the achievements of human intellect and human power.

CONTENTS

MODES OF TRAVELING

CONVEYANCE OF THOUGHT

LABOR-SAVING MACHINERY

LIGHT AND ITS USES

ASTRONOMY

GEOLOGY

PHYSICAL GEOGRAPHY

CHEMISTRY

CELEBRATED AND UNIQUE MANUSCRIPT AND BOOK ILLUSTRATIONS.

A series of fac-similes, showing the development of manuscript and book illustrating during a thousand years.

ANTIQUE VASE PAINTING.

A Rehearsal in an Early Greek Theatre.

As the modern drama is a development from the religious mystery plays of the Middle Ages, so the Greek drama was an outgrowth from the religious exercises of the worship of the god Dionysos. Both comedy and tragedy were considered of divine origin, and both originated in the dithyramb of Dionysos—by turns a merry song, celebrating the gift of the vine and the license of intoxication, and a funeral chant in memory of the sufferings of the god slain by the Titans, his descent into the kingdom of Hades and his subsequent return to earth.

The upper picture is from a vase of the form known as Aryballus, and represents the deity surrounded by his followers. The vase was exhumed in Athens, and is now in the Berlin Museum. The lower portion is from a vase in the Museum at Naples. In the centre is the actor who represents the god, and presides over the festival; he lies upon a couch with Ariadne beside him. The figure on his left holding a mask is the Muse of Tragedy, to whom a small winged attendant is presenting a wreath. Beyond the muse are Hercules and Silenus. On the other side are an unidentified hero and several actors. In front are the members of the chorus, dressed as satyrs. One of them is practising the characteristic dance, under the supervision of the chorus-master, who is seated and holds a baton.

THE WERNER COMPANY, AKRON, O.

ILLUSTRATIONS

MODES OF TRAVELING

Primitive and Modern Locomotion

By ALFRED RUSSEL WALLACE

WE men of the nineteenth century have not been slow to praise it. The wise and the foolish, the learned and the unlearned, the poet and the pressman, the rich and the poor, alike swell the chorus of admiration for the marvelous inventions and discoveries of our own age, and especially for those innumerable applications of science which now form part of our daily life, and which remind us every hour of our immense superiority over our comparatively ignorant forefathers.

But though in this respect (and in many others) we undoubtedly think very well of ourselves, yet, in the opinion of the present writer, our self-admiration does not rest upon an adequate appreciation of the facts. In order to estimate its full importance and grandeur—more especially as regards man's increased power over nature, and the application of that power to the needs of his life to-day, with unlimited possibilities in the future—we must compare it, not with any preceding century, or even with the last millennium, but with the whole historical period—perhaps even with the whole period that has elapsed since the stone age.

Looking back through the long dark vista of human history, the one step in material progress that seems to be really comparable in importance with several of the steps we have just made, was, when Fire was first utilized, and became the servant and the friend instead of being the master and the enemy of man. From that far distant epoch even down to our day, fire,

in various forms and in ever-widening spheres of action, has not only ministered to the necessities and the enjoyments of man, but has been the greatest, the essential factor, in that continuous increase of his power over nature, which has undoubtedly been a chief means of the development of his intellect and a necessary condition of what we term civilization. Without fire there would have been neither a bronze nor an iron age, and without these there could have been no effective tools or weapons, with all the long succession of mechanical discoveries and refinements that depended upon them. Without fire there could be no rudiment even of chemistry, and all that has arisen out of it. Without fire much of the earth's surface would be uninhabitable by man, and much of what is now wholesome food would be useless to him. Without fire he must always have remained ignorant of the larger part of the world of matter and of its mysterious forces. He might have lived in the warmer part of the earth in a savage or even in a partially civilized condition, but he could never have risen to the full dignity of intellectual man, the interpreter and master of the forces of nature.

Having thus briefly indicated our standpoint, let us proceed to sketch in outline those great advances in science and the arts which are the glory of our century. In the course of our survey we shall find that the more important of these are not mere improvements upon, or developments of, anything that had been done before, but that they are entirely new departures, arising out of our increasing knowledge of and command over the forces of the universe. Many of these advances have already led to developments of the most startling kind, giving us such marvelous powers, and such extensions of our normal senses, as would have been incredible, and almost unthinkable even to our greatest men of science, a hundred years ago. We begin with the simplest of these advances, those which have given us increased facilities for locomotion.

The younger generation, which has grown up in the era of railways and of ocean-going steamships, hardly realize the vast change which we elders have seen, or how great and fundamental that change is. Even in my own boyhood the wagon

for the poor, the stage coach for the middle class, and the post-chaise for the wealthy, were the universal means of communication, there being only two short railways then in existence—the Stockton and Darlington opened in 1825, and the Liverpool and Manchester line opened in 1830. The yellow post-chaise, without any driving seat, but with a postilion dressed like a jockey riding one of the pair of horses, was among the commonest sights on our main roads; and together with the hundreds of four-horse mail and stage coaches, the guards carrying horns or bugles which were played while passing through every town or village, gave a stir and liveliness and picturesqueness to rural life which is now almost forgotten.

When I first went to London (about 1835) there was still not a mile of railroad in England, except the two above named, and none between London and any of our great northern or western cities were even seriously contemplated. The sites of most of our great London railway termini were then on the very outskirts of the suburbs.

A few years later, while the London and Birmingham Railway, the precursor of the present London and Northwestern system, was in process of construction; and when the first section was opened to Watford, I traveled by it to London, third-class, in what is now an ordinary goods truck, with neither roof nor seats, nor any other accommodation than is now given to coal, iron, and miscellaneous goods. If it rained, or the wind was cold, the passengers sat on the floor and protected themselves as they could. Second-class carriages were then what the very worst of the third class are or were a few years ago—closed in, but low and nearly dark, with plain wooden seats—while the first-class were exactly like the bodies of three stage coaches joined together. The open passenger trucks were the cause of much misery, and a few deaths from exposure, before they were somewhat improved; but even then there was evidently a dread of making them too comfortable, so a roof was put to them, also seats, and the sides a little raised but open at the top, about equal in comfort to our present cattle trucks. At last, after a good many years, the despised third-class passengers were actually provided with carriages of the early sec-

ond-class type; and it is only in comparatively recent times that the greater railway companies realized the fact that third-class passengers were so numerous as to be more profitable than the other two combined, and that it was worth while to give them the same comfort, if not the same luxury, as those who could afford to travel more expensively.

The continuous progress in speed and comfort is matter of common knowledge, and nothing more need be said of it here. The essential point for our consideration is, the fundamental and even revolutionary nature of the change that has been wholly effected during the present century. In all previous ages the only modes of traveling or of conveying goods for long distances were by employing either men or animals as the carriers. Wherever the latter were not used, all loads had to be carried by men, as is still the case over a large part of Africa, and as was the case over almost the whole of America before its discovery by the Spaniards.

But throughout Europe and Asia the horse was domesticated in very early times, and was used for riding and in drawing war-chariots; and throughout the Middle Ages pack-horses were in universal use for carrying various kinds of goods and produce, and saddle horses for riding. All journeys were then made on horseback, and it was in comparatively recent times that wheeled vehicles for traveling came into general use in England. The very first carriage was made for Queen Elizabeth in 1568; the first that plied for hire in London were in 1625, and the first stage coaches in 1659.

But chariots drawn by horses were used, both in war and peace, by all the early civilized peoples. Pharaoh made Joseph ride in a chariot, and he sent wagons to bring Jacob, with his children and household goods, to Egypt. A little later, chariots were sent by the Syrians as tribute to Pharaoh. Homer describes Telemachus as traveling from Pylos to Sparta in a chariot provided for him by Nestor:

> The rage of thirst and hunger now suppress'd,
> The monarch turns him to his royal guest;
> And for the promis'd journey bids prepare
> The smooth-haired horses, and the rapid car.

It is clear, therefore, that in the earliest historic times all the various types of wheeled vehicles were used—for war, for racing, for traveling, and for the conveyance of merchandise. They must also have been used throughout a large part of Europe, since Cæsar found our British ancestors possessed of war-chariots, which they managed with great skill, implying a long previous acquaintance with the domesticated horse and its use in humbler wheeled vehicles.

Thus, throughout all past history the modes of traveling were essentially the same, and an ancient Greek or Roman, Egyptian or Assyrian, could travel as quickly and as conveniently as could Englishmen down to the latter part of the eighteenth century. It was mainly a question of roads, and till the beginning of the nineteenth century our roads were for the most part far inferior to those of the Romans. It is, therefore, not improbable that during the Roman occupation of Britain the journey from London to York could have been made actually quicker than a hundred and fifty years ago.

We see, then, that from the earliest historic, and even in prehistoric times, till the construction of our great railways in the second quarter of the present century, there had been absolutely no change in the methods of human locomotion; and the speed for long distances must have been limited to ten or twelve miles an hour even under the most favorable conditions, while generally it must have been very much less. But the railroad and steam-locomotive, in less than fifty years, not only raised the speed to fifty or sixty miles an hour, but rendered it possible to carry many hundreds of passengers at once with punctuality and safety for enormous distances, and with hardly any exposure or fatigue. For the civilized world traveling and the conveyance of goods have been revolutionized, and by means which were probably neither anticipated nor even imagined fifty years before.

Dr. Erasmus Darwin, who predicted steam carriages, had apparently no conception of the possibility of railroads, the enormous cost of which would have seemed to be prohibitory. And we have by no means yet fully developed their possibilities, since even now a railroad could be made on which we

might safely travel more than a hundred miles an hour, it being merely a question of expense.

In steam navigation there has been a very similar course of events, with the same characteristic of a completely new departure, leading to unknown developments and possibilities. From the earliest dawn of history, men used rowing or sailing vessels for coasting trade or for crossing narrow seas. The Carthaginians sailed nearly to the equator on the west coast of Africa, and in the eleventh century the Northmen reached North America on the coast of New England. Over five hundred years ago, Vasco de Gama sailed from Portugal round the Cape of Good Hope to India, and in the next century Columbus and his Spanish followers crossed the Atlantic in its widest part to the West Indies and Mexico. From that time sailing ships were gradually improved, till they culminated in our magnificent frigates for war purposes and the clipper ships in the China and Australian trade, which were in use up to the middle of the century. But during all this long course of development there was no change whatever in principle, and the grandest three-decker or full-rigged clipper ship was but a direct growth, by means of an infinity of small modifications and improvements, from the rudest sailing boat of the primeval savage.

Then, at the very commencement of the present century, the totally new principle of steam propulsion began to be used, first experimentally and with many failures, on rivers, canals, and lakes, till about the year 1815 coasting steamships of small size came into pretty general use. These were rapidly improved; but it was not till the year 1838 that the Great Western, of 1,340 tons and four hundred horse-power, made the passage from Bristol to New York in fourteen days, and thus inaugurated the system of ocean steam navigation which has since developed to such an enormous extent. The average speed then attained, of about ten miles an hour, has now been more than doubled, and is still increasing. But the horse-power needed to attain this high speed has increased in much greater proportion; and it is only the much greater size and capacity, both for passengers and goods, that render such high

speeds and enormous consumption of coal profitable. Some of the smaller steel-built war-ships—torpedo-boats and torpedo-destroyers—have considerably exceeded thirty miles an hour, and the limit of speed is probably not yet reached. Many suggested forms of vessels, such as the cigar-shaped and the roller boats, have not been adequately tried; and there are other suggested forms by means of which greater steadiness and speed may yet be obtained.

Almost as remarkable as our railroads and steamships is the new method of locomotion by means of the bicycle and tricycle. The principle is old enough, but the perfection to which these vehicles have now attained has been rendered possible by the continuous growth of all kinds of delicate tools and machines required in the construction of the infinitely varied forms of steam-engines, dynamos, and other rapidly moving machinery. In the last century it would not have been possible to construct a modern first-class bicycle, even if any genius had invented it, except at a cost of several hundred pounds. The combination of strength, accuracy, and lightness would not then have been attainable. It is a very interesting fact that three out of the four methods of rapid locomotion we now possess should have attained about the same maximum speed. The race-horse, the steamship, and the bicycle, have each of them reached thirty miles an hour. The horse is, however, close upon, if it has not actually attained, its utmost limits; the bicycle can already beat the horse for long distances, and will certainly go at higher speeds for short ones; while the steamship will also go much quicker, though how much no one can yet say. The greatest possibilities are with the bicycle, driven by electric power or compressed air, by which means, on a nearly straight and fairly level asphalt track, no doubt fifty miles an hour will soon be reached.

We see, then, that during the nineteenth century three distinct modes of locomotion have been originated and brought to a high degree of perfection. Two of them, the locomotive and the steamship, are altogether different in principle from what had gone before. Up to the very times of men now living, all our locomotion was on the same old lines which had been used

for thousands of years. It had been improved in details, but without any alteration of principle and without any very great increase of efficiency. The principles on which our present methods rest are new; they already far surpass anything that could be effected by the older methods; with wonderful rapidity they have spread over the whole world, and they have in many ways modified the habits and even the modes of speech of all civilized peoples.

This vast change in the methods of human locomotion, already so ubiquitous that by the younger generation their absence rather than their presence is considered remarkable, has been almost wholly effected within the writer's memory.

MODES OF TRAVELING

The Motor Vehicle

By RAY STANNARD BAKER

STEP up and take your seat in the world's very newest and most marvelous vehicle—the motor carriage. As you sit facing forward, where the horse ought to be and is not, your right hand fits easily and naturally over the smooth handle of a lever. Press your thumb down hard on a little button at the top and a bell rings sharply—a mere friendly warning that you are about to start. Now push the lever forward one notch and off you go, smoothly and steadily, but slowly; another notch, and you are making the speed of a trotting horse; still another notch, and you are flying like the wind, far faster than any horse ever goes under harness. While your right hand is thus employed with the speeding lever, your left is firmly holding the steering handle, swinging the vehicle, this way and that, around corners and past obstacles as easily as if it were a bicycle. If you wish to stop suddenly, your foot is on a brake; a slight push and the vehicle comes to a standstill.

Variations there are in the arrangement of levers and brakes in different vehicles, but they are all equally simple of management. You can travel from daylight to dark and never suffer with a worn-out horse; you can run away from the dust and escape the flies, and if you reach a railroad crossing just as a train is passing, your motor carriage never takes fright and runs away. When you reach home there is no troublesome unharnessing, nor rubbing down, and your carriage is ready at a second's notice to start on a new expedition. And as for the carriage whip, it will follow the horse out of existence.

Only a few years ago, in 1894, there were not thirty of these remarkable vehicles in practical use in all the world. At the beginning of 1898 there were not thirty in all America. And yet so great was the success of the inventor, and so widespread the interest of the public, that the manufacture of motor vehicles suddenly became a great industry. In the first four months of the year 1899 alone, corporations with the enormous aggregate capitalization of more than $300,000,000 were organized in New York, Boston, Chicago, and Philadelphia; and in many cities of the East, motor vehicles have become so familiar on the streets that they are noticed hardly more than horse carriages. More than that, motor ambulances, motor trucks, motor gun-carriages, motor stages, and motor fire engines are in operation in various cities. In France and England the motor vehicle has become an established and powerful factor in the common affairs of life. France has a powerful motor vehicle or "automobile" club which gives frequent races and exhibitions. At a single gathering more than 1,500 vehicles were shown, representing every conceivable model, from milk-wagons to fashionable broughams and the huge brakes of De Dion and Bouton, which carry almost as many passengers as a railroad car. Some of the expert "drivers" of Paris have ridden thousands of miles in their road wagons, have climbed mountains, and raced through half of Europe, meeting new accidents, facing new adventures, and using strange new devices for which names have yet to be coined.

The motor races of Paris have been by far the most unique and remarkable that the world has ever seen. Both M. Réne de Knyff and Count Chasseloup-Laubat, of Paris, have made sixty miles an hour on an ordinary road track. Just think of it! Faster than the Empire State Express, and that with no advantage of steel rails nor level road-bed. But even the records of these two famous racers have been beaten by M. Jenatzy with his lightning carriage, "La Jamais Contente" ("The Never Content"). This wonderful vehicle is built of sheet iron in the form of a long cigar or torpedo, so that it plunges through the air like a dart. The wheels are very small and, of course, fitted with rubber tires. There is a manhole in

the top of the vehicle, where the driver sits. Just in front of it there is a little steering wheel and electrical meters to show the voltage and ampèrage of the current. To see "La Jamais Contente" one would think that no driver ever would dare to risk his life upon it. And, indeed, after the current is turned on and the wheels begin to revolve, it is either fly or burn, so tremendous is the power of the batteries.

At the famous record trial "La Jamais Contente" was towed out from Paris to the racing road by a humble petroleum car. M. Réne de Knyff gave the word to start. M. Jenatzy turned on the current and braced himself, leaning well forward, with his hands firmly clasping the steering wheel. The car moved off somewhat slowly at first, but after going about ten yards, literally bounded forward, the wheels for a moment almost leaving the track. There was a blue-gray streak down the road, a faint cloud of dust, and the famous carriage was making more than a mile a minute. The sound of the motor was described by a spectator as resembling the rustling of wings, and the car undulated like a swallow in flying, this no doubt being due to the action of the springs and the rubber tires. Nothing had ever before traveled on a common road at such a speed, and the spectators were anxious to know, not whether Jenatzy had broken the record, but by how much he had broken it. The wheels left two broad white tracks in the middle of the road, absolutely straight and converging in the distance like a line of rails. It was a remarkable exhibition of accurate steering. Indeed, if Jenatzy had swerved an inch to the right or to the left, he would not have survived to tell the tale. After the trial was over, it was found that "La Jamais Contente" had made sixty-six miles an hour, and M. Jenatzy went away declaring that he should soon make seventy-five miles an hour.

In general it may be said that France has led in gasoline vehicles, and England in steam vehicles, while America, as was to be expected, has been far in the lead in electrical conveyances of all kinds. Belgium and Germany, and to some extent Austria, have also been experimenting with more or less success, but no such progress has been made in these countries as

in France. It was not until 1898 that Spain rubbed its eyes for the first time at the sight of a motor vehicle, which rolled through Madrid with half a dozen little policemen careering after it.

In a general way, it may be said that the best modern motor vehicle, whatever its propelling power, is practically noiseless and odorless and nearly free from vibrations. It is still heavy and clumsy in appearance, although it is lighter than the present means of conveyance when the weight of the horse or horses is counted in with the carriage. And invention will soon lighten it still further. It cannot possibly explode. It will climb all ordinary hills, and on a level road it will give all speeds from two miles an hour up to twenty or more. Its mechanism has been made so simple that any one can learn to manage it in an hour or two. And yet it is mechanism; and intelligence, coolness, and caution are required to manage a motor vehicle in a crowded street. The operator must combine the intelligence of the driver with that of the horse, and he does not appreciate the almost human sagacity of that despised animal until he has tried to steer a motor vehicle down Fifth Avenue on a sunny afternoon.

Seven different motive powers are now actually employed in this country: electricity, gasoline, steam, compressed air, carbonic-acid gas, alcohol, and liquid air. The first three of these have been practically applied with great success; all the others are more or less in the experimental stage.

The electric vehicle, which has had its most successful development in this country, has its well-defined advantages and disadvantages. It is simpler in construction and more easily managed than any other vehicle: one manufacturer calls it "fool-proof." It is wholly without odor or vibrations and practically noiseless. It will make any permissible rate of speed, and climb any ordinary hill. On the other hand, it is immensely heavy, owing to the use of storage batteries; it can run only a limited distance without recharging, and it requires a moderately smooth road. In cost it is the most expensive of all vehicles. And yet for city use, where a constant supply of electricity can be had, electrical cabs, carriages, and

delivery wagons have demonstrated their remarkable practicability.

The vital feature of the electric vehicle is the storage battery, which weighs from 500 to 1,500 pounds, the entire weight of the vehicles varying from about 900 to 4,000 pounds. A phaeton for ordinary private use will weigh upwards of a ton, with a battery of nine hundred pounds. This immense weight requires exceedingly rigid construction and high-grade, expensive tires. The electrical current is easily controlled by means of a lever under the hand of the driver, the propelling machinery being comparatively simple. When the battery is nearly empty, it may be recharged at any electric-lighting station by the insertion of a plug, the time required varying from two to three hours. Or, if the owner prefers, he can own his own charging plant and generate his own electricity: it will cost him from $500 to $700. The current not only operates the vehicle, but it lights the lamps, rings the gong, and in cabs and broughams actuates a push-button arrangement for communication between passenger and driver. The limit of travel without recharging is from twenty to thirty miles. A good electric carriage for family use cannot be obtained for much less than $2,000, although one or two manufacturers advertise runabouts and buggies at from $750 to $1,500. An omnibus costs from $3,000 to $4,000.

The company which operates the electric cab system in New York has a most extensive charging plant. Two batteries are provided for each vehicle, so that, when one is empty, it may be removed by the huge fingers of a traveling crane, placed on a long table, and recharged at leisure, while a completely filled battery is introduced in its place. This change takes only a few minutes, and the cab can be used continuously day and night.

The "lightning cabby" is a product of the new industry. He wears a blue uniform somewhat resembling that of a fireman, and he is a cool-headed, intelligent fellow, who can make ten miles an hour in a crowded street without once catching the suspicious eye of a policeman. Most of the "cabbies" have had previous experience as drivers, but they are given a very

thorough training before they are allowed to venture on the streets with a vehicle of their own. A special instructor's cab is in use by the company. It has a flaring front platform with a solid wooden bumper, so that it may crash into a stone curb or run down a lamp post without injury. The new man perches himself on the seat behind, and the instructor takes his place inside, where he is provided with a special arrangement for cutting off the current or applying the brakes, should the vehicle escape from the control of the learner. It usually takes a week to train a new man so that he can manage all the brakes and levers with perfect presence of mind. Both of his hands and both of his feet are fully employed. With his left hand he manages the power lever, pushing it forward one notch at a time to increase the speed. With his right hand he controls the steering lever, which, by the way, turns the rear wheels and not the front ones, as is done with horse-propelled vehicles. His left heel is on the emergency switch, and his left toe rings the gong. With his right heel he turns the reversing switch, and he may apply the brake with either his right or his left foot. When he wishes to turn on the lights, he presses a button under the edge of the seat. Hence, he is very fully employed, both mentally and physically. He cannot go to sleep and let the old horse carry him home.

In France the system of instruction for drivers or *chauffeurs* (stokers), as they are called, is much more complicated and extensive, but hardly more thorough. There the cab company has prepared a seven-hundred-yard course up hill and down, and paved it alternately with cobbles, asphalt, wooden blocks, and macadam, so as to give the incipient "cabby" experience in every difficulty which he will meet in the streets of Paris. Upon the inclines are placed numerous lay figures, made of iron—a typical Parisian nursemaid with a bassinet; a bicycle rider; an old gentleman presumably deaf, who is not spry in getting out of the way; a dog or two, and paper bricks galore. Down through this throng must the motorman thread his way and clang his gong, and he is not considered proficient until he can course the full length of the "Rue de Magdebourg," as the cabbies call it, without so much as over-

turning a singly pastry cook's boy or crushing a dummy brick.

New York cabs will run twenty miles without recharging. But it is not at all infrequent for a new man to have his vehicle stop suddenly and most unexpectedly; the current deserts him before he knows it. He must let the central office know at once, and the ambulance cab comes spinning out, hooks to the helpless vehicle, and drags it into the charging station. One manufacturer has issued lists of hundreds of central stations throughout New England, New York, and other Eastern States where automobiles may be provided with power.

In Belgium a company has recently been formed to establish electric posting stations. Its promoters plan to have a bar and restaurant connected with the charging plant, a regular medical attendant, and an expert mechanic who will know how to remedy all the ills of motor vehicles. In the larger cities the time must soon come when there will be coin-in-the-slot "hydrants" for electricity at many public places, from which owners of vehicles may charge their batteries while they wait.

A number of prominent New York physicians own their own motor vehicles, these being especially adapted to the varied necessities of a physician's practice. A motor vehicle is always ready at a moment's notice—it does not have to be harnessed. It can work twenty-four hours a day. When it is left in the street outside, the doctor takes with him a little brass plug, or key, without which the vehicle cannot run away or be moved or stolen. And, moreover, it is swifter by half than the ordinary means of locomotion, so that in emergency cases it may mean the saving of a life. One New York physician recently put an electric cab to a most extraordinary use. His patient had a broken arm, and he wished to photograph the fracture with Röntgen rays, but there was no source of electricity available in the residence of the patient. So he made a connection with the battery in his cab, which stood at the door; the rays were promptly applied, and the injury was located.

While the electric vehicle has been winning plaudits for its work in the cities, where pavements are smooth and hard, the gasoline vehicle has been equally successful both in the city

and in the country. For ordinary use the gasoline-propelled vehicle has many important advantages. It is much lighter than the electric vehicle; it requires no charging station, gasoline being obtainable at every cross-roads store; and it is moderately cheap. All of the famous long-distance races and rides in Europe have been made in gasoline vehicles. On the other hand, most of the gasoline vehicles are subject to slight vibrations due to the motor, and it is almost impossible to do away entirely with the unpleasant odors of burnt gases. Gasoline vehicles are never self-starting, it being necessary to give the piston one turn by hand. In general, also, they are not as simple of management as the electric vehicle; there is more machinery to understand and to operate, and more care is necessary to keep it in order. But when once the details are mastered, the traveler can go almost anywhere on earth with his gasoline carriage: up hill and down, over the roughest roads, through mud and snow, a law unto himself. He can make almost any speed he chooses.

The power principle of the gasoline vehicle is very simple. It is a well-known fact that when gasoline is mixed with air in proper proportions and ignited, it explodes violently. By admitting this mixture at the end or head of the engine cylinder, and exploding it at the proper moment, the piston is driven violently forward, and then, by the action of the fly-wheel or an equivalent device, it is forced back again, and the motor is kept in motion. Most gasoline engines are of what is known as the four-cycle variety. During the first impulse of the piston the vapor is drawn into the end of the cylinder, during the second it is compressed by the return of the piston, in the third it is exploded, and in the fourth the products of the combustion are driven out, and the end of the cylinder is ready for another charge. The explosion of the gas is produced in the most approved motors by means of an electric spark, there being no fire anywhere connected with the machine. Owing to the constant compression of the gases and the succeeding explosions, a gasoline motor becomes highly heated, and in order to maintain a normal temperature, it must be provided with a jacket of cold water, or a peculiar ribbed arrangement of

iron for increasing the radiating surface. A vast number of ingenious devices are used for making all of these processes as simple as possible. One motor is so arranged that no igniter is necessary, the gas being compressed in the cylinder to such a degree that it explodes of its own heat, thereby doing away entirely with electricity or any other sparking device. In France, most of the gasoline vehicles are still provided with what are known as "carburetters," or small chambers where the gas and air are mixed in the proper proportions and heated before they are driven into the cylinder. In this country, carburetters have been largely done away with, the gas being mixed as it passes into the cylinder.

Every driver of a gasoline vehicle must know these general facts about the mechanism of his motor. He must know how to fill the gasoline and water tanks, how to replenish or regulate the battery which ignites the gas, and he must understand the ordinary processes of cleaning and oiling machinery. When he is ready to start, he must connect up the sparking device and turn the wheel controlling the piston until the explosions begin. After that, he must see that the valves which admit the air and the gas are carefully adjusted, so that the mixture is admitted to the cylinder in the proper proportions, and then he is ready to go ahead, steering and controlling his engine by means of levers, and operating the brake and gong with his feet. All gasoline vehicles are provided with numerous means of stopping, besides the ordinary use of the brake, so that there is practically no possible danger of a runaway. The Duryea vehicle, for instance, has no fewer than five different means of turning off the power of the motor, all within convenient reach. The secretary of the company that manufactures this vehicle said he had often stopped his carryall within twenty feet, when going at a speed of twenty miles an hour, without great inconvenience to the passengers. By a clever arrangement for changing gearings, the gasoline vehicle can be made to ascend almost any hill, and it can be turned in half the space necessary for a horse vehicle.

It is astonishing how little fuel it takes to run a gasoline vehicle. One manufacturer showed a phaeton weighing seven

2

hundred pounds which he said would run one hundred miles on five gallons of gasoline, a bare half-dollar's worth. A tricycle manufactured by the same company, weighing one hundred and fifty pounds, will run eighty miles on three pints of gasoline.

Gasoline vehicles vary in cost over an even wider range than electrical vehicles. A tricycle can be obtained as low as $350, while an omnibus may cost into the thousands. A first-class road carriage built with all the latest improvements and highly serviceable in every respect, can be obtained for $1,000. At this price, the manufacturers assert that gasoline power is much cheaper than horse-power. One motor-vehicle expert has made some interesting comparisons, based on an average daily run of twenty-five miles for five years—more than the maximum endurance of a first-class horse. His estimates represent ordinary city conditions, and rate the cost of the gasoline used at one-half cent a mile:

GASOLINE MOTOR VEHICLE.

Original cost of vehicle, ...	$1,000.00
Cost of operation, 1 cent per mile, 25 miles per day, ...	456.50
New sets of tires during five years, . .	100.00
Repairs on motor and vehicle, . . .	150.00
Painting vehicle four times, ...	100.00
Storing and care of vehicles, $100.00 per year,	500.00
	$2,306.50

HORSE AND VEHICLE.

Original cost of horse, harness, and vehicle, .	$500.00
Cost of keeping horse, $30.00 per month, five years, ...	1,800.00
Repairs on vehicle, including rubber tires, .	150.00
Shoeing horse, $3.00 a month, five years, .	180.00
Repairs on harness, $10.00 per year, . .	50.00
Painting vehicle four times, ...	100.00
	$2,780.00

"At the end of five years," explained this expert, "the motor vehicle should be in reasonably good condition, while the

value of the horse and carriage would be doubtful. There is always the possibility that at least one of the horses may die in five years, while the motor vehicle can always be repaired at a comparatively nominal cost. But even assuming that the relative value of each is the same at the end of five years, the cost of actual maintenance during that period would be $1,306.50 for the motor vehicle and $2,280 for the horse and vehicle, or $973.50 in favor of the motor vehicle. This comparison is really doing more than justice to the horse, because a motor vehicle can do the work of three horses without injury."

Steam has been successfully applied to the heavier grades of vehicles, notably trucks, fire-engines, and omnibuses; and two or three American manufacturers have gone still further, and have produced light and natty steam buggies and runabouts, and even steam tricycles. Steam vehicles are easily started and stopped, and fuel and water are always readily obtainable; but there is also the disadvantage of a slight cloud of steam escaping from the exhaust, accompanied by more or less noise. Moreover, in many states there are regulations (mostly unenforced in the case of motor vehicles) against the operation of steam-engines except by licensed engineers, and it is probable that steam automobiles will not be widely accepted for pleasure purposes until the inventors have succeeded in producing automatic engines.

Much has been said as to the use of compressed air for heavy trucks, and several immense corporations have been organized to promote its use. The air is compressed at a central station, and admitted to heavy steel storage bottles, or tubes, connected with the truck and used much like steam. The main difficulty in the process has been the sudden cooling of the machinery when the air is released from pressure and begins to take up heat. Often the pipes and valves are frozen solid. To deal with this problem, a jacket of water heated by a gasoline flame is provided for "reheating" the air, a difficult and cumbersome process. Owing to the weight of the steel tubes, the compressed-air vehicles are enormously heavy, and, like electric vehicles, they must return to some charging station, after traveling twenty or thirty miles, for a new supply

of power. And yet both inventors and financial promoters are sanguine of ultimate success with them.

A Chicago inventor has been building a truck in which he combines gasoline and electrical power. An eight-horse-power gasoline engine situated over the front axle drives an electrical generator, which in turn feeds a small storage battery, thus producing power as the vehicle moves, and rendering it entirely independent of a charging station. One man can handle the entire truck, and it is said that the cost of operation will not exceed eighty cents a day. The main objection to this system, as with compressed air, is the enormous weight of the vehicle, which is upwards of 9,000 pounds. The truck has a carrying capacity of eight tons, making a total of 25,000 pounds. Such a vehicle presents problems which modern pavement builders have yet to solve.

But the time is certainly coming, and that soon, when all heavy loads must be drawn by automobiles. Recent English experiments, already mentioned, have established the feasibility of the auto-truck even in its present experimental stage, and the inventor needs no further encouragement to prosecute his work. It is hardly possible to conceive the appearance of a crowded wholesale street in the day of the automatic vehicle. In the first place, it will be almost as quiet as a country lane—all the crash of horses' hoofs and the rumble of steel tires will be gone. The vehicles will be fewer and heavier, although much shorter than the present truck and span, so that the streets will appear much less crowded. And with larger loads, more room, and less necessary attention, more business can be done, and at less expense.

A New York manufacturer produces an odd variation of the motor vehicle in what he calls a "mechanical horse." It is a one- or three-wheeled equipment provided with an electric motor, and it can be attached to almost any kind of carriage or wagon body and used for propulsion like a veritable mechanical horse.

As to what form the future motor vehicle will take there is the widest diversity of opinion. Business clashes with art. Horse carriages are built high so that the driver can see over

the horse and avoid the dust. The first motor vehicles were merely "carriages-without-the-horse," and some of them looked clumsy and odd enough, "bobbed off in front," as one enthusiast told me.

The utility of the automobile in any city is in direct proportion to the condition of its streets. It is hardly surprising that manufacturers are receiving the greatest number of inquiries from cities like Buffalo and Detroit, where the pavements are good, and from California and part of New England. The automobile has had such acceptance in France because the highways are all as smooth as park paths. Bicycling already has had a profound influence in spurring the road-makers, and the introduction of the motor vehicle will be still more effective. Colonel Waring estimated that two-thirds of all street dirt is traceable to the horse. At present it costs New York nearly $3,000,000 a year to clean its streets. With new pavements such as the new soft-tired vehicles and the absence of pounding hoofs would make possible, street cleaning would become a minor problem. And new asphalt pavement could be put down at the rate of forty miles a year for what New York now spends for half cleaning its streets.

As yet American law-makers have hardly touched on the subject of motor vehicles. In New York, if drivers keep out of Central Park, display a light, ring a gong, and do not speed faster than eight miles an hour, no one interferes with them. Similar regulations prevail in Boston, and in other American cities. In Brooklyn the parks are free. France and England, on the other hand, hedge in automobile drivers with all manner of rules and regulations, and require them to be officially licensed. In France, by recently promulgated articles, every type of vehicle employed must offer complete conditions of security in its mechanism, its steering gear, and its brakes. The constructors of automobiles must have the specifications of each type of machine verified by the *Service des Mines*. After a certificate of such verification has been granted, the constructor is at liberty to manufacture an unlimited number of vehicles. Each vehicle must bear the name of the constructor, an indication of the type of machine, the number of the

vehicle in that type, and the name and domicile of its owner. No one may drive an automobile who is not the holder of a certificate of capacity signed by the prefect of the department in which he resides.

The regulations are most explicit on the important question of speed. In narrow or crowded thoroughfares the speed must be reduced to walking pace. In no case may the speed exceed eighteen and one-half miles an hour in the open country, or twelve and one-half miles an hour when passing houses. Relative to signals, the regulations say that "the approach of an automobile must, if necessary, be signaled by means of a trumpet." Each automobile must be provided with two lamps, one white, the other green. Racing is allowed, provided an authorization is obtained from the prefect and the mayors are warned. In racing, the speed of eighteen and one-half miles an hour may be exceeded in the open country, but when passing houses, the maximum of twelve and one-half miles must not be exceeded.

One curious difficulty in connection with the new vehicle is the difficulty of finding suitable English names to designate it and its driver. The French, with characteristic readiness in getting settled names for things, have, as already noted, formally adopted the word "automobile," for the vehicle and "chauffeur" (stoker) for the driver. But we of the English tongue are slower. At least a dozen names have been used to a greater or less extent, such as "motor carriage," "auto-carriage," and "horseless carriage." In England, "self-propeller" is popular and so is "auto-car," the latter being apparently the favored designation. "Motor vehicle" seems to be the more generally accepted name in this country. But whatever it is, or is yet to be called, the thing itself must now be rated an accepted and established appliance of every-day life.

Since this article was written, there have been American records of seventy, eighty, and eighty-five miles an hour, in speed tests made on prepared tracks and on country roads. There have also been a number of fatalities among driving parties and persons riding or walking on the streets and roads.

MODES OF TRAVELING

The Flying Machine

By RAY STANNARD BAKER

FLYING-MACHINE inventors and enthusiasts may be divided into two great classes, each of which is certain that it has discovered the only straight and narrow path to aerial navigation. Those who belong to the first of these classes place their faith in the steerable or dirigible balloon; they secure their lifting power with gas, and seek to control the direction of flight by various contrivances of wings and screw propellers. They are air soarers. Those of the second class go to the bird for their model. The bird, they assert, is nature's first and best flying machine; and if a bird, which is nearly a thousand times as heavy as the air it displaces, can soar for hours aloft without tiring, why shouldn't a man do the same, provided he can build the proper mechanism? Consequently these inventors, who have given the subject of bird flight long and serious attention, discard the balloon system with something of disdain, and plan their machines after the perfect model of a bird's wing.

Both of these methods have been thoroughly tested, and, what is more, with astonishing success, considering the difficulties which have had to be overcome. Balloon flying machines have really been steered, not to the limits of success, but far enough to demonstrate that the feat can be accomplished. On the other hand, a soaring or aeroplane machine has been constructed and actually made to fly for considerable distances; and yet more curious and interesting, a number of daring in-

ventors have constructed real wings with which they have soared with success from hill-tops and high walls.

Both of these methods are, therefore, worthy of careful consideration, although I now take up only flying machines proper —the aeroplanes and bird-like contrivances—the balloon machines or air floaters coming more properly under the important subject of ballooning.

I suppose more inventors have been fascinated with the idea of building a machine that would fly than with almost any other single subject, perpetual motion possibly excepted. Nearly every town has its flying-machine enthusiaast, and the Patent Office at Washington is busy constantly with curious designs for winged mechanisms; and yet the perfect machine, the machine which will one day supplant the steamship, bankrupt the railroad, and annihilate space, is yet to be invented. And invented it positively will be, for mathematicians have demonstrated its possibility by unerring figures, and it only remains for the clever mechanician to build the necessary machinery.

Probably no American inventor of flying machines is so well known for his experiments as Professor S. P. Langley, the distinguished secretary of the Smithsonian Institution at Washington. He has built a machine with wings, driven by a steam-engine, and wholly without gas or other lifting power beyond its own internal energy. And this machine, to which has been given the name aerodrome (air runner), actually flies for considerable distances. So successful were Professor Langley's early tests, that the United States Government recently made a considerable appropriation to enable him to carry forward his experiments in the hope of finally securing a practical flying machine.

The invention of the aerodrome was the result of long years of persevering and exacting labor, with so many disappointments and setbacks that one cannot help admiring the astonishing patience which kept hope alive to the end. Early in his experiments, Professor Langley had proved positively, by mathematical calculations, that a machine could be made to fly, provided its structure were light enough and the actuating

power great enough. Therefore he was not in pursuit of a mere will-o'-the-wisp. It was a mechanical difficulty which he had to surmount, and he surmounted it.

Professor Langley made his first experiments more than twelve years ago at Allegheny, Pennsylvania. He began, not by building a flying machine, but with a thorough investigation into the theory of the flight of birds, in order to find out how much power was needed to sustain a surface of given weight by means of its motion through the air. For this purpose he built a very large "whirling table"—a device having an arm which swept around a central pivot, the outer end of which could be given a velocity of seventy miles an hour. Various objects were hung at the end of the arm and dragged through the air, until its resistance supported them just as a kite is supported by the wind. A plate of brass weighing one pound, for instance, was hung from the end of the arm by a spring, which was drawn out until it registered a pound weight when the arm was still. When the arm was in motion, it might be expected that, as it was drawn faster, the pull would be greater; but Professor Langley's observations, strangely enough, showed just the contrary, for under these circumstances the spring contracted until it registered less than an ounce. With the speed increased to that of a bird in flight, the brass plate seemed to float on the air. Preliminary experiments of this nature were continued for three long years, and Professor Langley formed the general conclusion that by simply moving any given weight in plate form fast enough in a horizontal path through the air it was possible to sustain it with very little power. It was proved that, if horizontal flight without friction could be insured, two hundred pounds of plates could be moved through the air and sustained upon it at the speed of an express train, with the expenditure of only one horse-power, and that, of course, without using any gas to lighten the weight.

Every boy who has skated knows that when the ice is very thin he must skate rapidly, else he may break through. In the same way, a stone may be skipped over the water for considerable distances. If it stops in any one place it sinks instantly. In exactly the same way, the plate of brass, if left in any one

place in the air, would instantly drop to the earth; but if driven swiftly forward in a horizontal direction it rests only an instant in any particular place, and the air under it at any single moment does not have time to give way, so to speak, before it has passed over a new area of air. In fact, Professor Langley came to the conclusion that flight was theoretically possible with engines he could then build, since he was satisfied that engines could be constructed to weigh less than twenty pounds to the horse-power, and that one horse-power would support two hundred pounds if the flight was horizontal.

That was the beginning of the aerodrome. Professor Langley had worked out its theory, and now came the much more difficult task of building a machine in which theory should take form in fact. In the first place, there was the vast problem of getting an engine light enough to do the work. A few years ago an engine that developed one horse-power weighed nearly as much as an actual horse. Professor Langley wished to make one weighing only twenty pounds, a feat never before accomplished. And then, having made his engine, how was he to apply the power to obtain horizontal speed? Should it be by flapping wings like a bird, or by a screw propeller like a ship? This question led him into a close study of the bird compared with the man. He found how wonderfully the two were alike in bony formation, how curiously the skeleton of a bird's wing was like a man's arm, and yet he finally decided that flapping wings would not make the best propeller for his machine. Men have not adopted machinery legs for swift locomotion, although legs are nature's models, but they have rather constructed wheels—contrivances which practically do not exist in nature. Therefore, while Professor Langley admits that successful flying machines may one day be made with flapping wings, he began his experiments with the screw propeller.

There were three great problems in building the flying machine. First, an engine and boilers light enough and at the same time of sufficient power. Second, a structure which should be rigid and very light. Third, the enormously difficult problem of properly balancing the machine, which, Professor Langley says, "took years to acquire."

For his propelling power he tried compressed air, gas, electricity, carbonic-acid gas, and many other sources of energy, but he finally settled on the steam-engine, and he succeeded, after all manner of difficulties, in building a mechanism light enough. He says in regard to this part of the work:

"The chief obstacle proved to be not with the engines, which were made surprisingly light after sufficient experiment. The great difficulty was to make a boiler, of almost no weight, which would give steam enough, and this was a most wearying one. There must be also a certain amount of wing surface, and large wings weighed prohibitively; there must be a frame to hold all together, and the frame, if made strong enough, must yet weigh so little that it seemed impossible to make it. These were the difficulties that I still found myself in after two years of experiment, and it seemed at this stage again as if it must, after all, be given up as a hopeless task, for somehow the thing had to be built stronger and lighter yet. Now, in all ordinary construction, as in building a steamboat or a house, engineers have what they call a factor of safety. An iron column, for instance, will be made strong enough to hold five or ten times the weight that is ever going to be put upon it; but if we try anything of the kind here, the construction will be too heavy to fly. Everything in the work has got to be so light as to be on the edge of breaking down and disaster, and when the breakdown comes, all we can do is to find what is the weakest part and make that part stronger; and in this way work went on, week by week and month by month, constantly altering the form of construction so as to strengthen the weakest parts, until, to abridge a story which extended over years, it was finally brought nearly to the shape it is now, where the completed mechanism, furnishing over a horse-power, weighs collectively something less than seven pounds. This does not include water, the amount of which depends on how long we are to run; but the whole thing, as now constructed, boiler, fire-grate, and all that is required to turn out an actual horse-power and more, weighs something less than one one-hundredth part of what the horse himself does."

From this it will be seen what tremendous difficulties had

to be met and solved, and yet the machine could not fly independently, although the mechanical power was there.

Professor Langley established an experimental station in the Potomac River, some miles below Washington. An old scow was obtained, and a platform about twenty feet high was built on top of it. To this spot, in 1893, the machine was taken, and here failure followed failure; the machine would not fly properly, and yet every failure, costly as it might be in time and money, brought some additional experience. Professor Langley found out that the aerodrome must begin to fly against the wind, just in the opposite way from a ship. He found that he must get up full speed in his engine before the machine was allowed to go, in the same way that a soaring bird must make an initial run on the ground before it can mount into the air, and this was, for various reasons, a difficult problem. And then there was the balancing.

"If the reader will look at the hawk or any soaring bird," says Professor Langley, "he will see that as it sails through the air without flapping the wing, there are hardly two consecutive seconds of its flight in which it is not swaying a little from side to side, lifting one wing or the other, or turning in a way that suggests an acrobat on a tight-rope, only that the bird uses its widely outstretched wings in place of the pole."

It must be remembered that air currents, unlike the Gulf Stream, do not flow steadily in one direction. They are forever changing and shifting, now fast, now slow, with something of the commotion and restlessness of the rapids below Niagara.

All of these things Professor Langley had to meet as a part of the difficult balancing problem, and it is hardly surprising that nearly three years passed before the machine was actually made to fly—on May 6, 1896.

"I had journeyed, perhaps for the twentieth time," says Professor Langley, "to the distant river station, and recommenced the weary routine of another launch, with very moderate expectation indeed; and when, on that, to me, memorable afternoon the signal was given and the aerodrome sprang into the air, I watched it from the shore with hardly a hope that

the long series of accidents had come to a close. And yet it had, and for the first time the aerodrome swept continuously through the air like a living thing, and as second after second passed on the face of the stop-watch, until a minute had gone by, and it still flew on, and as I heard the cheering of the few spectators, I felt that something had been accomplished at last; for never in any part of the world, or in any period, had any machine of man's construction sustained itself in the air before for even half of this brief time. Still the aerodrome went on in a rising course until, at the end of a minute and a half (for which time only it was provided with fuel and water), it had accomplished a little over half a mile, and now it settled, rather than fell, into the river, with a gentle descent. It was immediately taken out and flown again with equal success, nor was there anything to indicate that it might not have flown indefinitely, except for the limit put upon it."

Only a brief description of Professor Langley's machine can here be given. It has two pairs of wings, each slightly curved, attached to a long steel rod from which hang the boilers, engines, and other machinery, and the propeller wheels. The hub itself is formed of steel tubing; in front there is a little conical float to keep the machine from sinking, should it fall in the water. The boiler weighs a little over five pounds, while the engine, which gives one and one-half horse-power, weighs only twenty-six ounces. The rudder is arranged for steering in four directions—up, down, to the right, and to the left, and all automatically.

The width of the wings from tip to tip is between twelve and thirteen feet, and the length of the whole about sixteen feet. The weight is nearly thirty pounds, of which about one-fourth is the machinery.

So much for Professor Langley's aerodrome, the first and most wonderful of machines of its kind. Hiram Maxim, the famous inventor of the Maxim gun, has experimented on a colossal affair of aeroplanes to carry three men—and she ran swiftly when her wheels rested firmly on the wide rails of her little railroad, but her inventor never has ventured to lift her free in the air. These two inventions, Langley's and Maxim's,

have been the greatest efforts toward the utilization of the soaring plane.

The possibility of using wings for flight is one of the very oldest of mechanical ideas. It is so easy to say, "A bird flies; why shouldn't a man?" and more than one brilliant inventor has been dashed to death trying to answer this very question. What boy hasn't read of the amusing adventures of Darius Green? And yet of late years, wonderful enough, men *have* actually flown with wings, wings resembling those of a soaring bird. Only a year or two ago Lilienthal, the famous "flying man" of Berlin, was killed from a fall received while he was careering high above the earth with his great wings. Chanute, an American inventor, has flown successfully with wings; and only recently Hargrave, the Australian inventor of the famous box-kite, has been making kite-like wings which he asserts will solve the great problem of practical aerial navigation.

Lilienthal, the flying man, built his wings after a long and close study of the flight of birds. He finally came to the conclusion that a bird is able to sustain itself without apparent effort in the air, and even to soar against the wind, owing to the peculiar curved surface of its wings. The fins of many fishes and the web feet of aquatic birds are strikingly analogous in construction. The sails of a ship assume a similar form. It would be impossible to sail so near the wind in beating if the instrument of propulsion were a rigid flat surface. It is the effort of the sail to get away from the wind which it gathers in its ample bosom which drives the boat forward, almost in the very teeth of the breeze. The flying machine devised and used by Herr Lilienthal was designed rather for *sailing* than for *flying*, in the proper sense of the term; or, as he once said, "for being carried steadily and without danger, under the least possible angle of descent, against a moderate wind, from an elevated point to the plain below." It was made almost entirely of closely woven muslin, washed with collodion to render it impervious to air, and stretched upon a ribbed frame of split willow, which was found to be the lightest and strongest material for this purpose. Its main elements were the arched wings; a vertical rudder, shaped like a palm-leaf fan, which acted as a

LANGLEY'S AERODROME.

vane in keeping the head always towards the wind; and a flat, horizontal rudder, to prevent sudden changes in the equilibrium.

The operator so adjusted the apparatus to his person that, when in the air, he either rested on his elbows or was seated upon a narrow support near the front. With the wings folded behind him, he made a short run from some elevated point, always against the wind, and when he attained sufficient velocity, launched himself into the air by a spring or jump, at the same time spreading the wings, which were at once extended to their full breadth, whereupon he sailed majestically along like a gigantic seagull. In this way Herr Lilienthal often accomplished flights of three hundred yards and more from the starting-point.

"No one," Herr Lilienthal once explained, "can realize how *substantial* the air is until he feels its supporting power beneath him. It inspires confidence at once. With flat wings it would be almost impossible to guard against a fall. With arched wings it is possible to sail against a moderate breeze at an angle of not more than six degrees to the horizon."

The principle is recognized in the umbrella form universally adopted for the parachute. Try to run with an open umbrella held above the head and slightly inclined backward, and see what a lifting power it exerts.

Lilienthal spent many years of toil on his invention, and after his final perfected wings were finished, it required much skill and strength to use them successfully, to guide the direction of flight by careful movements of the arms, to go up by leaning back, and down by leaning forward. And at the last the inventor himself was hurled to his death, but not until he had contributed much to the knowledge of aeronautics.

Mr. Hargrave has contributed to scientific information a very clear statement as to why a bird is able to soar against the wind, and he is using his discoveries as the basis for a new invention in flying machines. Hargrave's idea is that the thick forward part of a bird's wing acts as an obstruction, like a dam in a river, causing a whirlpool below the wing, which rolls with great force against the back side of this obstruction, thereby forcing it forward. In other words, progress through the air

is caused by an undertow of air. He suggests, therefore, a flying machine shaped somewhat in the form of a toboggan turned upside down. The wind, striking the edge of the toboggan curve in front, creates a whirlpool in the inverted hollow, and propels the whole machine forward and upward, according to the way it is steered by the suspended ballast, which determines its angle of flight.

Each year the inventor presses closer to the great secret of human flight, each year the mechanic is able to build more perfect machinery, and the two, working side by side, may be expected before many years have passed to produce a flying machine which will be practically a success as well as an experimental success.

Great interest was stirred by the success of a young gentleman from Brazil, M. Santos-Dumont, in navigating a dirigible balloon round the Eiffel tower in Paris. Several times he demonstrated the possibility of constructing machines large enough to carry several persons and follow a course independently of mild air currents.

A Santos-Dumont balloon has been tried at Coney Island, where it was sailed for a mile or so in conditions less favorable than they would have been had the experiment not been made impromptu. About the same time, September, 1902, a well-known aeronaut of London, Stanley Spencer, surprised every one by making a trip of thirty miles, unannounced, from the Crystal Palace, by a curved course over South London to Harrow, without accident. He repeatedly lowered his machine to within a few hundred feet of the earth, and changed its direction and speed at will. His balloon was oblong, with the motor at the front end, like the wings of a dragon-fly.

MODES OF TRAVELING

What Keeps the Bicycler Upright?

By CHARLES B. WARRING

THERE is something weird, almost uncanny, in the noiseless rush of the cyclist, as he comes into view, passes by, and disappears. Pedestrians and carriages are left behind. He yields only to the locomotive and to birds. The apparent ease and security of his movement excite our wonder. We have seen rope-walkers, and most of us have tried to walk on the top rail of a fence, and have a vivid recollection of the incessant tossing of arms and legs to keep our balance, and the assistance we got from a long stick or a stone held in our hands. But the cyclist gets no help. His legs move only in the tread of the wheel, and his hands rest quietly on the ends of the cross-bar of his machine. The rope-walker keeps every muscle tense, and every limb in motion or ready to move. No wonder, when a tourist on his bicycle spins for the first time through a village here, or among the nomads of Asia, he is followed by a gaping crowd, till his machine carries him out of their sight.

We involuntarily ask, How is it possible for one supported on so narrow a base to keep his seat so securely and, seemingly, so without effort?

For an answer to this question I have searched somewhat widely, and, while I have found articles enough on or about the bicycle, and what has been done by its riders, I have found none that offered a reasonable theory for its explanation. This is my apology for presenting the present paper. In it I shall state the theories which have been offered, the reasons why

they are unsatisfactory, and then give what appears to me the true *rationale* of the machine.

The only paper I found that claimed to explain the bicycle was one by Mr. C. Vernon Boys, entitled "The Bicycle and its Theory." It was delivered before a meeting of mechanical engineers, and is reported at great length in "Nature," vol. xxix. But, on examination, I found that, out of several pages of closely printed matter, the Theory occupied possibly a dozen lines. All the rest was about the bicycle and what had been done on it, but not another word about its theory. We are told that Mr. Boys exhibited a top in action, and requested his audience to notice its remarkable stability. Then he said that the stability of the bicycle was due to the same principle, but made no attempt to show any connection between them. The top revolves on its axis, and it stays up as you see; the wheel of the bicycle revolves on its axis, and therefore it stays up, was his theory and demonstration, and the whole of it, and, so far as one can judge from the report, he was satisfied, however it may have been with his audience.

Of all machines, none seem to be so little understood as the top and its near relation, the gyroscope. Hence the best that can be said is, that the lecturer availed himself of the tendency found in most minds to "explain" an unfamiliar phenomenon by referring it to some other more familiar one, longer known, but equally incomprehensible—as if, as in grammer, two negatives make an affirmative, so, in physics, two unknowns make a known.

Without going into the theory of the top, or of the gyroscope, it is easy to show experimentally that their stability and that of the bicycle must be due to different principles. I spin on this table a top with a somewhat blunt point (Fig. 1). You notice it runs around in a circular or rather a spiral path, and gradually rises to a perpendicular. I strike it quite a hard blow, but do not upset it. I send it flying across the table, or off to the floor, but still it maintains its upright position. You notice that, when it is perpendicular, it stands still; but, if it leans ever so little, it immediately begins to swing or gyrate around a vertical axis. I now change the top for one whose

point is very fine and well centered and sharp (Fig. 2). You see that it hardly travels at all. I now cause the point to fall into a slight pit in the surface of the table: it ceases to travel, but continues for a very considerable time to swing around a vertical axis, and is remarkably stable, whatever the angle at which it leans. Stopping its traveling has, as you see, no effect upon its stability; but now I put my pencil before the axle and stop the gyration or swinging around. Immediately the power of staying up is gone, and the top falls. I may vary the experiment in every possible way: so long as the axis is inclined, the result is the same; the moment the gyration ceases, the top falls.

In the case of the bicycle there is no gyrating around a vertical axis. Whatever else it may do, it does not do that.

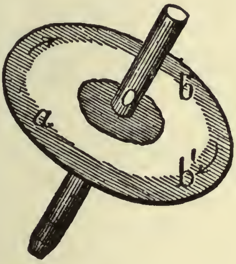


Fig. 1.

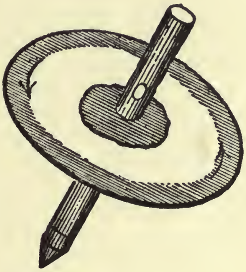


Fig. 2.

Yet, as you saw, gyration is absolutely essential to the effect which Mr. Boys thinks accounts for its stability.

We may, I think, dismiss the top from further consideration; but there is another instrument apparently much closer in its relation to the bicycle. I mean the gyroscope, or rather that form of it which Lord Kelvin calls a gyrostat. Its wheel is upright like the bicycle's (see Figs. 3 and 4). The lower part of the ring which supports the wheel rests in a kind of trough, to the bottom of which is attached crosswise a piece of metal (best seen in Fig. 3) curved on the lower edge, and with two projecting wires by which it may be drawn back and forth in the plane of the wheel.

I now set the wheel in rapid motion—much more rapid than

any bicycle-wheel can go; I place it on a smooth, hard surface—I have here a pane of glass—and leave it to itself. It begins at once, as you see, to revolve around a vertical axis. If it leans little, it revolves slowly; if it leans much, it revolves faster. It will not fall to the table, though I push it, or strike a hard blow. It resists with remarkable force. I now take it by the projecting wires and attempt to make it move in a straight course, as a bicycle does when it spins along the road. Instantly it falls. The rotation of the wheel on its axis was not in the slightest degree interfered with, but the stability vanishes the moment the rotation around the vertical axis

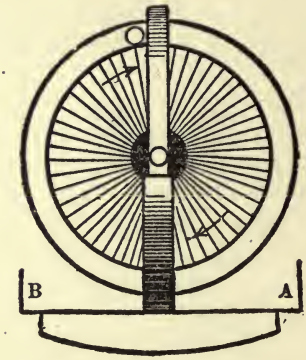


Fig. 3.

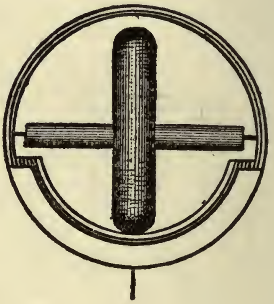


Fig. 4.

ceases. Invariably it falls. Yet you observe the conditions are far more favorable for the effect of gyrostatic action than in the bicycle, for the mass of the rim of our gyrostat is many times heavier in proportion to its size, and its speed incomparably greater. I try the experiment over and over, the result is always the same. No amount of skillful management will make the instrument stay up for an instant if it has to move in a straight line. I submit that these experiments are proof positive that the sustaining power of the bicycle does not come from any gyroscopic action.

Others find in its going so fast the reason why the bicycle does not fall—referring, of course, in a blind way to that principle embodied by Newton in his first law: "A body in motion,

if left to itself, will continue to move in a straight line forever." A brief examination will, I think, convince you that this, too, fails to account for the effect which we know is somehow produced.

It is another principle in physics that two forces acting at right angles to each other do not interfere. Each produces its own effect as fully as if the other did not act. Now, in case of a bicyclist, his forward motion, whether fast or slow, is at right angles to gravity, hence does not in any way resist it; and, therefore, as it is gravity that causes him to tilt over, the forward motion will not prevent his falling.

But it may be said that the force of gravity when the 'cycle leans, say to the right, is in fact resolved into two components, one vertical and the other lateral, and it is the latter only that causes the bicyclist to fall. This does not help the matter, for both components are perpendicular to the course of the bicycle, and hence its forward motion can in no way counteract either of them. Unless some other force comes into play, the bicyclist must fall toward whichever side he happens to begin to lean.

Many think they find this counteracting influence in "centrifugal force." You all are familiar with the effects of this "force." You feel them every time you turn a corner quickly, whether on foot or in a wagon, or on horseback. The bareback riders in the circus lean well toward the center of the ring, to escape being thrown outward. We see its effect when the bicyclist spins around a corner. In such cases "centrifugal force" plays an important part, and is the real upholding force.

But centrifugal force is impossible so long as the body moves in the same direction, i.e., in a straight line. There must be change of direction, and, other things being equal, this force is greater in proportion to the abruptness of that change; or, as mathematicians say, the velocity being constant, it varies inversely as the radius of the curve in which the body moves. The larger the radius, the smaller the centrifugal force. If the radius of curvature becomes infinite—i.e., the curve becomes a straight line—the centrifugal force becomes infinitely small or zero.

So long, therefore, as the bicyclist does not turn corners—keeps in a straight course—the centrifugal force gives us no assistance whatever in understanding why he keeps his seat so securely. But yet it may be thought that this force, if supplemented by skillful balancing, is sufficient. It keeps the bicycle from falling when turning corners: will not good balancing account for the stability when moving in a straight course? We are all familiar with the phenomena of balancing one's self. We know the help a heavy pole gives at such times; how a person's legs and arms move with startling rapidity in the opposite direction to that in which he feels himself falling. There is nothing of this on the wheel. If the stability was due to balancing, it would not be so very difficult for a bicyclist to sit upon his machine when not in motion, and when its wheels both point in the same direction. I have never seen one that could do it. I suspect, however, that it is not impossible, any more than to stand on the top round of an unsupported ladder. But the ordinary bicyclist cannot do it; and yet, without apparent effort, he rides securely. That his stability is not due to his balancing and to his rapid forward motion combined, is evident when we reflect that if the handles are made immovable, so that neither of the wheels can be turned to the right or left, it is impossible for any ordinary rider, no matter at what speed he may move, to keep from falling for any considerable time after he once begins to tilt.

Apparently the fact that some can ride "hands off" on a safety wheel contradicts this, for, however it may be on an "ordinary," on a "safety" the rider cannot guide it by the pedals, and as he does not touch the handles of the steering-wheel or the wheel itself, it would seem that his not tilting must be due to good balancing. Experiment, however, proves the contrary. Let the steering wheel be fixed by tying the handles, or by a clamp on the spindle, so that it cannot turn to the right or the left, and then let the cyclist try to keep it erect. Balancing won't help, except possibly to delay his fall a few moments. And worse than that, he can't ride hands off at all if he tries to do so only by balancing. The explanation of such riding is not very difficult, but requires some other

matters to be treated first. At present all I desire to establish is that in this kind of riding, as well as in all others, the rider's ability to keep from falling to one side for an indefinite time while traveling in a straight line is not due to balancing.

I think you will agree with me that the reasons thus far assigned for the stability of the bicycle cast little or no light upon the subject. Gyration has nothing to do with it; centrif-

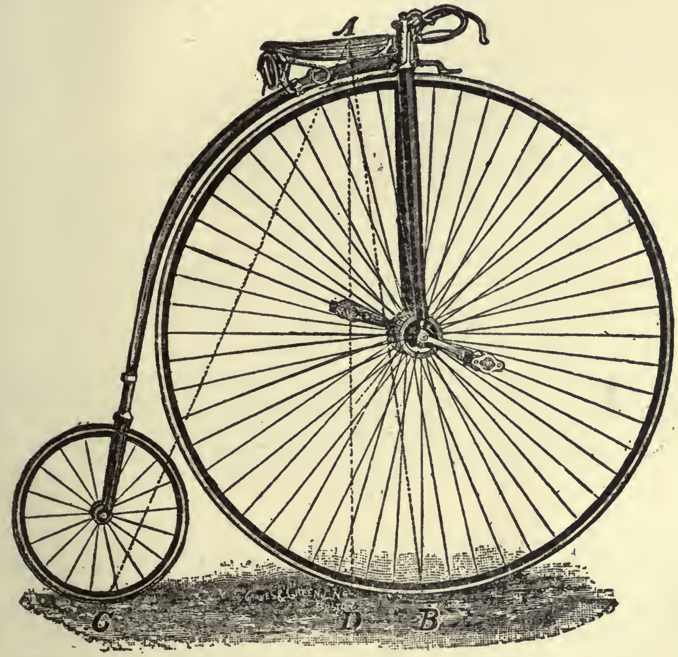


Fig. 5.

ugal force has no application to it, except when turning corners, or otherwise changing abruptly the direction of the movement; balancing is a detriment rather than an assistance; and rapid motion alone accounts for nothing. Some other explanation is needed; this I shall now attempt to give.

Regarded mathematically as a machine for the application of force, the bicycle is a very simple affair. The weight (Figs. 5 and 6) is applied at the saddle, A, and is so great that the

center of gravity of the whole is very close to that point. A B and A C are the lines of force, B marking the point where the fore wheel rests on the ground, and C where the rear one. In discussing the forces that act on the machine we need consider only these lines, all the other parts being merely for convenience or ornament. It is evident that A cannot of itself tilt either backward or forward, since a vertical line from it falls between B and C. In reference to them it is in stable equi-

Fig. 6.

librium, while in regard to side motion its equilibrium is very unstable; the least thing will upset it.

To study the matter more conveniently, I have had a form made which eliminates all unnecessary parts and represents only the lines of force and the weight on the saddle (Fig. 7). It consists, as you see, of two long, slender pieces of pine, and looks like a huge capital A, the cross-piece serving merely to hold the whole more firmly together. At the apex, A, I have placed a few pounds of lead to represent the rider's weight.

In the older form of the bicycle, the wheel in front is very much larger. The corresponding leg, A B (Fig. 7), is much steeper and shorter than the other. In "safety cycles" it is just the reverse, the rear leg being steeper and shorter, while

the two wheels are of nearly the same size. As the theory of both machines is the same, I shall, for the present, speak only of the former.

For convenience in handling, and that it may be better seen, I place the foot C, the rear one, on the table, and hold the other, B, in my hand, and at the same height from the floor. Now, notice: the weight at the apex, or saddle, begins to tilt to the right; I quickly move my hand to the right till it comes under the weight. If the saddle tilts to the left, I move my hand quickly to the left. In every case, by moving my hand more rapidly than the weight tilts, I bring the point of

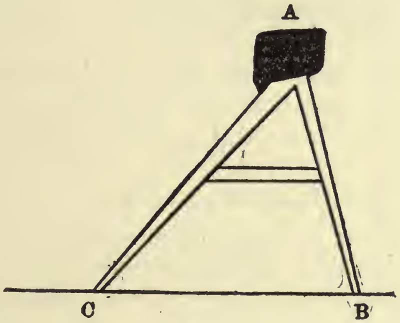


Fig. 7.

support under it. It is very easy in this way to keep the weight from falling; and that is the way the bicycle is kept upright.

But you will ask, How can the rider move the point of support when it is on the ground, and several feet out of his reach? He does it by turning the wheel to the right or left, as may be necessary—that is, by pulling the cross-bar to the right or left, and thus turning the forked spindle between whose arms the steering-wheel is held and guided.

But, some one will say, How does turning the wheel bring the point of support to the right or left—whichever the machine may happen to be leaning?

Let us suppose a 'cyclist mounted on his wheel and riding, say, toward the north. He finds himself beginning to tilt

toward his right. He is now going not only north with the machine, but east also. He turns the wheel eastward. The point of support, B (Fig. 5), must of necessity travel in the plane of the wheel, hence it at once begins to go eastward, and, as it moves much faster than the rider tilts, it quickly gets under him, and the machine is again upright. To one standing at a distance, in front or rear, the bottom of the wheel will be seen to move to the right and left, just as I moved the foot of the skeleton frame a moment ago.

I conclude, then, that the stability of the bicycle is due to turning the wheel to the right or left, whichever way the leaning is, and thus keeping the point of support under the rider, just as a boy keeps upright on his finger a broomstick standing on its smallest end.

It may be questioned whether the bottom point of the wheel really travels faster than the weight at the saddle tilts over, and, if it does not, then the explanation which I have been giving fails.

By an easy calculation, based on the well-known principle that the velocity of a body moving under the influence of gravitation varies as the square root of the height from which it has fallen, irrespective of the character of the path it has described, I find that when the rider's seat is, e.g., sixty inches high, and the machine has inclined, say, six inches out of the perpendicular, it is at that instant, if free to fall, tilting over at the rate of much less than a mile an hour. But six inches is a large amount to lean—a good cyclist does not lean that much—we will suppose him out of plumb only three inches; then his lateral movement will be at the rate of only some twenty-two hundred feet in an hour. If the tilt is less, the falling rate will be less. To keep the center of gravity over the base, the bottom of the wheel needs only to move to the right or left, whichever the machine is leaning—somewhat faster than these slow rates. There is no great difficulty in doing this, for, if the bicycle is going eight miles an hour, it is necessary to change its course only about seven degrees; if four miles, then only about fourteen degrees; if two miles, then about twenty-eight degrees. The greater the speed, the less the angle: at sixteen

miles an hour, the wheel would need to be turned less than two degrees. From which follows the fact, well known to cyclists, that the slower the machine is traveling the more the handles must be turned, and the more difficult to keep from falling.

From the fact that the bicycle is kept erect by keeping its point of support under it, like a pole standing upright on one's finger, some curious and, to most persons, quite surprising results follow. I have here three rods, respectively one foot, three feet, and seven feet long. I hold the last, as you see, very easily; the second not so easily; and the first only with considerable difficulty. I now put a cap of lead weighing four or five pounds on the top of each, and then again support them as before. In every case it is now easier to keep them from falling. Hence, in a bicycle, the higher and the heavier the load, the less the danger of falling; and, as most of the weight is in the saddle, the center of gravity of the whole is very near it, and it is the height of that, and not the size of the wheel, that affects the lateral stability. A rider with a load on his back, whether a bag of grain or a man sitting on his shoulders, is by all that the more safe from falling either to the right or left, however it may be as to headers.

Experts sometimes ride for a considerable distance with both legs over the cross-bar. But there is nothing strange in this, for placing their legs in that position only raises the center of gravity, and hence really adds to the stability. If in some way they can manage to turn the cross-bar, they can ride without difficulty until the momentum is exhausted.

A much more difficult feat is to ride on one wheel. The small wheel—the rider holding the other in the air—is most easily managed. It is merely a case of supporting on a small base a long, upright body. One keeps moving the point of support so as to bring it under the center of gravity. It needs only a quick eye and a steady hand. It is much more difficult when the cyclist uses only the big wheel, the other having been removed, for he is liable to fall forward or backward, as well as to either side. To avoid the first and second, he leans forward a little beyond his base, and would pitch headlong, but that he drives the wheel forward by means of the treadles just fast

enough to prevent it. We all do the same thing when we walk. We lean so far forward that we would fall, did we not keep moving our feet fast enough to prevent it. On the single wheel most of us would fail, because from lack of experience we would make the wheel go too fast, and so would fall backward; or else, not fast enough to keep from falling on our faces. As to falling sidewise, that is prevented exactly as when both wheels are used—the rider turns the crossbar to the right or left, and propels the machine in that direction. Experience, a level head, and a steady hand tell how far to turn it.

From mere inspection of Figure 5 we see that safety against headers varies inversely as the height of the saddle, and directly as the distance from the foot of the perpendicular A D to the forward point of support B (Figs. 5 and 6). In other words, the higher the saddle, the greater the danger of headers; and the farther back, the less the danger.

As to the law of lateral safety—i.e., against falling sidewise—it is in one respect the reverse of the other, for the greater the height of the saddle, the easier not to fall to either side, just as it is easier to keep upright on the end of my finger a long stick than a short one.

CONVEYANCE OF THOUGHT

From Mail Coach to Telephone

By ALFRED RUSSEL WALLACE

THE history of the progress of communication between persons at a distance from each other has gone through three stages which are radically distinct. At first it was dependent on the voice or on gestures, and a message to a friend (or enemy) at a distance could be sent only through a messenger, and was liable to distortion through failure of memory. The heralds and ambassadors of early times thus communicated orders from kings to their subjects, or conveyed messages from one king to another. Then came the invention of writing, and a new era of communication began. Letters were capable of conveying secret information and copious details, which could not be safely intrusted to the uncertain memory of an intermediary; and a single messenger could convey a large number of letters to various persons on the way to his ultimate destination. Henceforth the progress of communications was bound up with that of locomotion, and, as civilization advanced, arrangements were made for the conveyance of letters at a comparatively small cost. A post-office for the public service was first established by some Continental merchants in the fourteenth century; but it was not till the time of Charles I. that anything of the kind was to be found in England, and then it was mainly for the purpose of keeping up a communication between London and Edinburgh, and the intervening large towns, for Government purposes. It was, however, the starting-point of our existing postal system, which has been gradually extended under the direction of the King's postmaster-

general, and has continued to be a government monopoly to our day. The letters were carried on horseback till 1783, when mail coaches were first introduced; and these led to a great improvement in our main roads, and the extension of the postal service to every town and village in the kingdom.

But even with good roads and mail coaches, the actual time taken in the dispatch of a letter to a distant place was little if any less than had been possible from the earliest times, by means of relays of runners on foot or by swift horsemen. The improvement consisted in the regularity and economy of the postal service. The introduction of railways and steamships enabled much greater speed to be secured; but the greatest and most beneficial improvement in the administration of the post-office was that inaugurated by Rowland Hill in 1840. The rule then first introduced, of a uniform charge irrespective of distance, is one of those entirely new departures so many of which characterize our century, and which not only produce immediate beneficial effects, but are the starting-points of various unforeseen developments. It was founded in this case on a careful estimate of the various items which make up the cost of the carriage and delivery of each letter, and it was shown that the actual conveyance, even for the greatest distances, was the smallest part of the cost when the number of letters is large, the chief items of expense being the office work—the sorting, stamping, packing, etc.—and the final delivery, all of which are quite independent of the distance the letter is carried. The old system, therefore, of increasing the charge for postage in proportion to distance was altogether unreasonable, because the cost of conveyance was hardly perceptibly increased; and if the post-office was considered to be a public service for the public benefit only, the people had a right to demand that they should pay only in proportion to the cost. Yet the principle was not at first, and is not even now, fully carried out. For thirty years, from 1840 to 1871, the postage was increased equally with each successive increment of weight, the half-ounce letter being a penny, while one of two ounces was four-pence. But as the chief items of expense—the office work and delivery—were the same, or nearly the same, in both

cases, the double or quadruple charge was entirely opposed to the principle on which the uniform rate was originally founded. Accordingly, in 1871, when an ounce letter was first carried for a penny, the charge for two ounces was fixed at three half-pence, while four ounces was taken for twopence. This accepted and common-sense principle, however, has not yet been applied to the charges of the Postal Union, so that a letter which is a fraction over the half-ounce is charged fivepence, or double, and one over an ounce and a half tenpence, or four times that of the half-ounce letter, although an extra halfpenny would probably cover the extra cost of the service in both cases.

The same inability of the official mind to carry out an admitted principle is seen also in the case of Postal Orders. The cost to the post-office of receiving and paying money is exactly the same whether the amount is eighteenpence or fifteen shillings, and there is neither justice nor common sense in charging three times as much in the latter case. There is no risk, because the money is paid in advance; and as the amounts taken in and paid out for postal orders must be approximately equal, it is difficult to see what justification there is for making any difference in charge. The same objection applies to money orders; and as there is doubtless a certain percentage of both which, from various causes, are never presented for payment, the profit to the post-office must be greater in case of the higher amounts, which is another reason why these should not be exceptionally taxed. When the railways are taken over by the state, to be worked for the good of the community only, the principle will admit of great extension, each increment of distance being charged at a lower rate, just as is each increment of weight in our inland letters.

The third stage in the means of communication, when by means of electric signals it was rendered independent of locomotion, is that which has especially distinguished the present century. The electric telegraph serves us as a new sense, enabling us to communicate with friends at the other side of the globe almost as rapidly and as easily as if they were in different parts of the same town. The means of communication we now

use daily would have been wholly inconceivable to our ancestors a hundred years ago.

About the middle of the last century it was perceived by a few students of electricity that it afforded a means of communication at a distance; but it was not till the year 1837 that the efforts of many simultaneous workers overcame the numerous practical difficulties, and the first electric telegraph was established. Its utility was so great, especially in the working of the railways then being rapidly extended over the kingdom, that it soon came into general use; but hardly any one at first thought that it would ever be possible to lay wires across the ocean depths to distant continents. Yet, step by step, with wonderful rapidity, even this was accomplished. The first submarine line was laid from Dover to Calais in 1851; and only five years afterward, in 1856, a company was formed to lay an electric cable across the Atlantic. The cable, 2,500 miles long and weighing a ton per mile, was successfully laid, in 1858, from Ireland to Newfoundland; but owing to the weakness of the electric current, and perhaps to imperfections in the cable, it soon became useless, and had to be abandoned. After eight years more of invention and experiment, another cable was successfully laid in 1866; and there are now no less than fourteen lines across the Atlantic, while all the other oceans have been electrically bridged, so that messages can be sent to almost any part of the globe at a speed which far surpasses the imaginary power of Shakespeare's sprite Ariel, who boasted that he could "put a girdle round about the earth in forty minutes." We are now able to receive accounts of great events almost while they are happening on the other side of the globe; and, owing to difference of longitude, we sometimes can hear of an event apparently before it has happened. If some great official were to die at Calcutta at sunset, we should receive the news in London soon after noon on the same day.

As a result of the numerous experimental researches necessitated for the continuous improvement of the electric telegraph, the telephone was invented, an even more marvelous and unexpected discovery. By it, the human voice, in all its

countless modifications of equality and musical tone, and its most complex modulations during speech, is so reproduced at a distance that a speaker or singer can be distinctly heard and understood hundreds of miles away. This is not an actual transmission of the voice, as in the case of a speaking-tube, but a true reproduction by means of two vibrating disks: the one set in motion by the speaker, while the electric current causes identical vibrations in the similar disk at the end of the line, and these vibrations reproduce the exact tones of the voice so as to be perfectly intelligible. At first telephones could only be worked successfully for short distances, but by continuous improvements the distance has been steadily increased, so that in America there is a telephone line now in operation between New York and Chicago, cities about a thousand miles apart.

Those who have read Mr. Bellamy's story, "Looking Backward," will remember the concerts continually going on day and night, with telephonic connections to every house, so that every one could listen to the very best obtainable music at will. But few persons are aware that a somewhat similar use of the telephone is actually in operation at Buda-Pesth in the form of a telephonic newspaper. At certain fixed hours throughout the day a good reader is employed to send definite classes of news along the wires which are laid to subscribers' houses and offices, so that each person is able to hear the particular items he desires, without the delay of its being printed and circulated in successive editions of a newspaper. It is stated that the news is supplied to subscribers in this way at little more than the cost of a daily newspaper, and that it is a complete success.

We thus see that during the present century two distinct modes of communication with persons at a distance have been discovered and brought into practical use, both of which are perfectly new departures from the methods which, with but slight modifications, had been in use since that early period when picture writing or hieroglyphics were first invented.

In the facilities and possibilities of communication with our fellow-men all over the world, the advance made in the present

century is not only immensely greater than that effected during the whole preceding period of human history, but is even more marvelous in its results. And it is also much greater in amount than the almost simultaneous advance in facilities for locomotion, great as these have been.

CONVEYANCE OF THOUGHT

Wireless Telegraphy

By RAY STANNARD BAKER

MARCONI was a mere boy when he first began to dream of the marvelous possibility of sending telegraph messages without wires. He was barely twenty-one, a shy, modest youth, when he went up to London from his quiet country home in Italy to tell the world about one of the greatest inventions of the century. A few months later this boy had set up his apparatus and was telegraphing all sorts of messages through the air, through walls, through houses and towns, through mountains, and even through the earth itself, and that with a mechanism hardly more complicated or expensive than a toy telephone. The present system of telegraphy by means of wires, the sending of long dispatches over continents and under oceans, is quite wonderful enough in itself, but here was an inventor who did away entirely with wires and all other means of mechanical connection, and sent his messages directly through space. It is for this that Marconi was famous the world over at twenty-five.

The young inventor is tall and slender, and dark of complexion. Although he bears an Italian name and was born in Bologna, Italy (in 1874), and educated at Bologna, Leghorn, and Florence, he is only half Italian, his mother being an Englishwoman. He speaks English readily and fluently, and he appears to like London better than his native land. His first experiments were carried on in the fields of his father's estate, and consisted merely of tin boxes set up on poles of varying heights, one of which was connected with a crude transmitting

machine, and the other with an equally crude receiver, which he himself had manufactured.

Before going into the details of Guglielmo, or William, Marconi's apparatus and telling more of his astonishing successes, it may be well to look somewhat into the theories on which he bases his work. It must be understood, however, that Marconi was not the first to suggest wireless telegraphy, nor to signal experimentally for short distances without wires; but he was the first to perfect a system and to put it into practical operation, and to him, therefore, belong the laurels of the invention. Our own Prof. S. F. B. Morse, the inventor of telegraphy, experimented with wireless signals, and so did Dr. Oliver Lodge and W. H. Preece of London, Thomas A. Edison, Nikola Tesla, Professor Trowbridge of Harvard, and others.

In sending messages through space, Marconi deals with that mysterious all-pervading substance known as the ether. In the English language the word "ether" has two totally different meanings. It is the name of a clear, colorless liquid, which is used in surgical operations for easing a patient of pain. Every one has heard of "taking ether." This liquid, however, has nothing to do with the present subject, and it should be entirely dismissed from the mind. The ether which carries Marconi's messages is a colorless, odorless, unseen, inconceivably rarefied substance which is supposed to fill all space. Scientists know almost nothing as to its properties, but they do know that it will vibrate, and they have called these vibrations electricity, heat, and light.

It seems strange enough that we should use the ether every time we build a fire under the tea-kettle, every time we read by the light of a gas-jet, every time we talk over the telephone, and yet know next to nothing about it.

Throw a stone into a pond and you will produce a series of small waves or ripples—in other words, water vibrations. Strike a bell, and vibrations in the air bring the sound to your ear. In a similar way ether has its own peculiar vibrations. For instance, a star millions of miles away starts the enormously rapid vibrations of light, and these vibrations finally reach our eyes, as the ripples in a pond reach the shore. We

do not really see the star; we are merely conscious of light waves in the ether. In the same manner ethereal vibrations bring us the heat and light of the sun, and the awful energy of the lightning stroke. From this we know that the ether extends everywhere through space, and that the sun and the earth and the stars are set in it, like cherries in a jelly. Light will pass through such a hard, brittle substance as glass, heat will go through iron, and electricity "flows" in a copper wire. These facts show us that the ether must be inside of the glass and the iron and the copper, else the vibrations would not go through. In the same way the air is full of ether, and so are our bodies and everything else, for science knows nothing which entirely resists the passage of heat, light, and electricity. We call some substances solids, owing to their hardness, but so far as the ether is concerned there is no such thing as a solid. Every atom, even of the hardest diamond, is afloat in ether.

But if heat, light, and electricity are all caused by ether waves, how can we tell them apart?

The larger the stone you throw into the pond the larger the waves produced and the more rapidly they travel. In a similar way, ether waves are of widely different lengths and rapidity or frequency. Vibrations of one speed give light, another speed give heat, and still another give electricity. Science has learned by a series of wonderful experiments that if the ether vibrates at the inconceivable swiftness of four hundred trillions of waves every second, we see the color red, if twice as fast we see violet. If more slowly, from two hundred to four hundred trillions to the second, we experience the sensation of heat. If more rapidly than violet, we have what science knows as "unseen light"—the actinic rays and, probably, X-rays. Our eyes will take in only seven colors with vibrations from four hundred to eight hundred trillions a second. If our eyes were better we might see other degrees of vibrations, such as X-rays and various electrical currents, and know new colors, stranger and more beautiful, perhaps, than any that we now see.

Ether waves should not be confused with air waves. Sound

is a result of the vibration of the air; if we had ether and no air we should still see and feel heat and electricity, but there would be nothing to hear. Air or sound waves are very slow compared with ether waves. A man's ordinary voice produces only about one hundred and thirty waves a second, a woman's shrill scream will reach 2,000 vibrations—a mere nothing compared with the hundreds of trillions which represent light. Nor do air waves travel as rapidly as ether waves. In a storm the ether brings the flash of the lightning long before the air brings the sound of thunder, as every one knows.

Now, to get down to electricity. Certain vibrations of the ether are recognized as electricity—and there are many kinds of electrical waves to correspond with different degrees of vibration. Inventors have been able to utilize electricity by producing these ether waves by artificial means. I have compared the ether to a jelly. The electrician merely jars this jelly, and the vibrations which we know as a "current" are produced. A current does not really pass through a telegraph wire—it does not flow like water in a pipe—although our common language has no other means of expressing its passage. In reality a vibration is started at one end of the wires, and it is the wave that travels. Set up a row of toy blocks. Tip over the first one, and it will tip over the second, and so on to the end. The blocks stay where they are, but the motion or wave goes onward to the end. An electric wave is, of course, invisible. Imagine a cork on the surface of a pond at any distance from the place where a stone is dropped; the cork, when the wave reaches it, will bob up and down. Now, though we cannot see the electric wave, we can devise an arrangement which indicates the presence of the wave exactly after the manner of a cork.

Electric waves were discovered in 1842 by Joseph Henry, an American. He did not use the phrase "electric waves"; but he discovered that when he produced an electric spark an inch long in a room at the top of his house, electrical action was instantly set up in another wire circuit in his cellar. There was no visible means of communication between the two circuits, and after studying the matter he saw and announced that the

electric spark set up some kind of an action in the ether, which passed through two floors and ceilings each fourteen inches thick, and caused "induction"—set up what is called an induced current—in the wires in the cellar. This fact of induction is now one of the simplest and most commonplace phenomena in the work of electricians. Edison has already used it in telegraphing from a flying train. Hertz, the great German investigator, developed the study of these waves, and announced that they penetrated wood and brick, but not metal. The "Hertzian wave" is, indeed, an important feature of wireless telegraphy. Strange to say, however, considering the number of brilliant electricians in the world, and the great interest in electrical phenomena, it was left to the young Italian, Marconi, to frame the largest conception of what might be done with electric waves, and to invent instruments for doing it.

Marconi's reasoning was exceedingly simple. The ether is everywhere; it is in the air and in the mountains and in houses as well as in a copper wire. Electricity must, therefore, pass through the air and the mountain as well as through the wire. The difficulty lay in making an apparatus that would produce a peculiar kind of wave, and to catch or receive this wave in a second apparatus located at a distance from the first. This he finally succeeded in doing by the use of waves similar to those produced by Hertz, which he excited in a specially constructed apparatus. These waves have a frequency of about two hundred and fifty millions every second. From the generating apparatus this peculiar current is communicated to a wire which hangs from the top of a long pole or mast, or from a kite, and it passes by induction, through miles of air and earth and buildings, to a second hanging wire, which conveys it to a receiving instrument, where the signals are registered. To understand this transfer we must understand exactly what induction means. An electrical current may be *conducted* through copper wire, water, iron, or any other good "conductor." In *induction* the current passes directly through the ether. When a current of electricity passes through a wire, magnetism is present around that wire; and if another wire be brought within the magnetic field of the charged wire and placed parallel with it, it will also

become charged with electricity. That is *induction*, and it enables Marconi to send his messages across the Channel from England to France, from ships on the sea to shore, from lighthouse to lighthouse, and across wide stretches of open country.

And now, having come to an understanding of the theory of sending messages without wires, we may take a look at Marconi's actual apparatus as it is now transmitting messages from the Needles in Alum Bay, at the extreme west end of the Isle of Wight, eighteen miles across the Channel, to Poole on the mainland of England.

From the very peak of Marconi's telegraph mast at the Needles hangs a line of wire that runs through a window into the little sending room. Here two matter-of-fact young men are at work as calmly as any ordinary telegraphers, talking through the ether. One of them has his fingers on a black-handled key. He is saying something to the Poole station eighteen miles away in England.

"Brripp—brripp—brripp—brrrrrr.
Brripp—brripp—brripp—brrrrrr—
Brripp—brrrrrr—brripp. Brripp—brripp!"

So speaks the sender with noise and deliberation. It is the Morse code working—ordinary dots and dashes which can be made into letters and words, as everybody knows. With each movement of the key, bluish sparks jump an inch between the two brass knobs of the induction coil, the same kind of coil and the same kind of sparks that are familiar in experiments with the Röntgen rays. For one dot, a single spark jumps; for one dash, there comes a stream of sparks. One knob of the induction coil is connected with the earth, the other with the wire hanging from the masthead. Each spark indicates a certain impulse from the electrical battery; each one of these impulses shoots through the wire, and from the wire through space by vibrations of the ether, traveling at the speed of light, or seven times around the earth in a second. That is all there is in the sending of these Marconi messages. Any person of fair intelligence could learn to do it, Morse code and all, in a few hours.

After sending a message the young operator switches on to the receiver, which is contained in a metal box about the size of a valise. The same perpendicular wire from the masthead serves to receive messages as well as to send them, but the instruments within the office for sending and for receiving are quite different.

The receiving apparatus is kept in a lead box to protect it from the influence of the sending machine, which rests beside it on the table. You can easily believe that a receiver sensitive enough to record impulses from a point eighteen miles away, might be disorganized if these impulses came from a distance of two or three feet. But the lead box keeps out these nearby vibrations.

The coherer is the part of the receiving apparatus which makes wireless telegraphy possible, and to it more than to anything else has Marconi given his attention. He did not make the first coherer, but he made the first one that was practically useful, and to this great and important invention he owes his success.

I will try to give a clear idea of what this coherer is like, and why it is so important. It consists of a tube made of glass, about the thickness of a thermometer tube, and about two inches long. It seems absurd that so tiny and simple an affair can come as a benefit to all mankind; yet the chief virtue of Marconi's invention lies here in this fragile coherer. But for this, induction coils would snap their messages in vain, for none could read them. In each end of this tube there is a silver plug, the two plugs nearly meeting within the tube. In the narrow space between the plugs nestle several hundred minute fragments of nickel and silver, the finest dust, siftings through silk, and these enjoy the strange property (as Marconi discovered) of being alternately very good conductors and very bad conductors for the Hertzian waves—very good conductors when welded together by the passing current to a continuous metal path, very bad conductors when they fall apart under a blow from the electrical tapper which is a part of the receiving apparatus. One end of the coherer is connected with the wire which hangs from the mast outside, the other with the earth

and also with a home battery that works the tapper and the Morse printing instrument.

And the practical operation is this: A single vibration comes through the ether, down the wire and into the coherer, causing the particles of metal to stick together or cohere (hence the name). Then the Morse instrument prints a dot, and the tapper strikes its little hammer against the glass tube. That blow jars apart or *decoheres* the particles of metal, and stops the current of the home battery. And each successive impulse through the ether produces the same curious coherence and decoherence, and the same printing of dot or dash. The impulses through the ether would never be strong enough of themselves to work the printing instrument and the tapper, but they are strong enough to open and close a valve (the metal dust), which lets in or shuts out the stronger current of the home battery—all of which is simple enough after some one has taught the world how to do it.

"We have telegraphed twenty-five miles from a ship to the shore," said Dr. Erskine-Murray, assistant to Marconi, "and in that distance the earth's dip amounts to about five hundred feet. If the curvature counted against us then, the messages would have passed some hundreds of feet over the receiving station; but nothing of the sort happened. So we feel reasonably confident that these Hertzian waves follow around smoothly as the earth curves."

"And you can send messages through hills, can you not, and in all kinds of weather?"

"Easily. We have done so repeatedly."

"Then if neither land nor sea nor atmospheric conditions can stop you, I don't see why you can't send messages to any distance."

"So we can," said the electrician—"so we can, given a sufficient height of wire. It has become simply a question now how high a mast you are willing to erect. If you double the height of your mast, you can send a message four times as far. If you treble the height of your mast, you can send a message nine times as far, and so on up. To start with, you may assume that a wire suspended from an eighty-foot mast will

send a message twenty miles. We are doing about that here."

"Then a mast one hundred and sixty feet feet high would send a message eighty miles."

"Exactly."

"And a mast three hundred and twenty feet high would send a message three hundred and twenty miles; a mast six hundred and forty feet high would send a message 1,280 miles; and a mast 1,280 feet high would send a message 5,120 miles?"

"That's right. So you see if there were another Eiffel Tower in New York, it would be possible to send messages to Paris through the ether and get answers without ocean cables."

"Do you really think that would be possible?"

"I see no reason to doubt it," answered Dr. Erskine-Murray. "What are a few thousand miles to this wonderful ether, which brings us our light every day from millions of miles away?"

One of the greatest of present difficulties is that of securing secrecy in the transmission of these ethereal messages. The vibrations from the perpendicular wires are transmitted equally well in every direction, exactly as circular waves are produced when a stone is thrown in the water. Therefore any one may set up a receiver anywhere within the range of the waves, and take the message. Thus, in times of war, communications between battleships or armies might be at the mercy of any one who had a Marconi receiver, although, of course, generals and admirals might use cipher despatches.

Marconi realizes the very great importance of sending messages in one and only one direction. Light waves can be reflected by a mirror, and thrown upon one particular spot. Every boy who has played in school with a bit of looking-glass knows this fact well. Now, electricity, which is also produced by vibrations in the ether, can also be reflected. Marconi has been experimenting with a copper reflector, by means of which he throws a peculiar kind of electrical wave directly through space to the distant receiver. In this way a message may be aimed in any direction by simply turning the reflector a little, and no one but the man at the receiver can know what is being sent. This exceedingly important feature of the work is, how-

ever, still in an experimental stage, and the inventor who is successful in making a really practical reflecting apparatus will win a fortune.

The practical uses of wireless telegraphy are many. In December, 1898, the English lightship service authorized the establishment of wireless communication between the South Foreland lighthouse at Dover and the East Goodwin lightship, twelve miles distant. This was installed in the usual way without difficulty, and has been in operation ever since, the lightship keepers learning to use the instruments in a few days. And before the apparatus had been up six months several warnings of wrecks and vessels in distress reached shore, when, but for the Marconi signals, nothing of the danger would have been known.

Another application of wireless telegraphy that promises to become important is the signaling of incoming and outgoing vessels. With Marconi stations all along the coast, it would be possible for all vessels within twenty-five miles of shore to make their presence known and to send or receive communications.

So apparent are the advantages of such a system that in May, 1898, Lloyds began negotiations with the Wireless Telegraph Company for setting up instruments at various Lloyds stations; and a preliminary trial was made between Bally-castle and Rathlin Island in the north of Ireland. The distance signaled was seven and a half miles, with a high cliff intervening between the two positions, and the results of many trials were absolutely satisfactory.

We come now to that historic week in March, 1899, when the system of wireless telegraphy was put to its most severe test in experiments across the English Channel between Dover and Boulogne. These were undertaken by request of the French Government, which was considering a purchase of the rights to the invention in France. At five o'clock on the afternoon of Monday, March 27th, everything being ready, Marconi pressed the sounding-key for the first cross-channel message. The transmitter sounded, the sparks flashed, and a dozen eyes looked out anxiously upon the sea. Would the message carry

all the way to England? Thirty-two miles seemed a long way!

Marconi transmitted deliberately a short message, telling the Englishmen that he was using a two-centimetre spark, and signing three V's at the end. Then he stopped, and the room was silent with a straining of ears for some sound from the receiver. A moment's pause, and then it came briskly, and the tape rolled off its message. There it was, short and commonplace enough, yet vastly important, since it was the first wireless message sent from England to the Continent: First "V," the call; then "M," meaning "Your message is perfect"; then, "Same here, 2 c m s. V V V.," the last being an abbreviation for two centimetres and the conventional finishing signal.

And so the thing was done; a marvelous new invention was come into the world to stay.

On the following Wednesday Marconi did a graceful thing by sending a complimentary message to M. Branly (in Paris), the inventor of the original coherer, which Marconi had improved upon. He also sent a long message to the Queen of Italy. More recently Marconi sent signal messages between England and Nova Scotia. Ships now exchange word-messages with each other on the ocean.

Mr. Moffett asked one of Marconi's chief engineers if there was not a great saving by the wireless system over cables.

"Judge for yourself," was the answer. "Every mile of deep-sea cable costs about $750; every mile for the land ends about $1,000. We save all that, also the great expense of keeping a cable steamer constantly in commission making repairs and laying new lengths. All we need is a couple of masts and a little wire. The wear and tear is practically nothing. The cost of running is simply the cost of home batteries and operators' keep."

"How fast can you transmit messages?"

"Just now at the rate of about fifteen words a minute; but we shall do better than that, no doubt, with experience."

"Do you think there is much field for the Marconi system in overland transmission?"

"In certain cases, yes. For instance, where you can't get

the right of way to put up wires and poles. What is a disobliging farmer going to do if you send messages right through his farm, barns and all? He can't sue the Hertzian waves for trespass, can he? Then see the advantage, in time of war, for quick communication, and no chance that the enemy may cut your wires."

"But they may read your messages."

"That is not so sure, for besides the possibility of directing the waves with reflectors, Marconi is now engaged in most promising experiments in syntony, which I may describe as the electrical tuning of a particular transmitter to a particular receiver, so that the latter will respond to the former and no other, while the former will influence the latter and no other. That, of course, is a possibility in the future, but it may soon be realized. There are even some who maintain that there may be produced as many separate sets of transmitters and receivers capable of working together as there are separate sets of Yale locks and keys. In that event, any two private individuals might communicate freely without fear of being understood by others. There are possibilities here, granting a limitless number of distinct tunings for transmitter and receiver, that threaten our whole telephone system—I may add, our whole newspaper system."

"Our newspaper system?"

"Certainly; the news might be ticked off tapes every hour right into the houses of all subscribers who had receiving instruments tuned to a certain transmitter at the news-distributing station. Then the subscriber would have merely to glance over their tapes, and they would learn what was happening in the world."

"Will the wireless company sell its instruments?"

"No, it will rent them on a royalty, as telephone companies do, except, of course, where rights for a whole country are absolutely disposed of."

There was further talk of the possibilities in wireless telegraphy, and of the services Marconi's invention may render in coming wars.

"If you care to stray a little into the realm of speculation,"

said the engineer, "I will point out a rather sensational rôle that our instruments might play in military strategy. Suppose, for instance, you Americans were at war with Spain, and wished to keep close guard over Havana harbor without sending your fleet there. The thing might be done with a single fast cruiser in this way: Supposing a telegraphic cable laid from Key West, and ending at the bottom of the sea a few miles out from the harbor. And supposing a Marconi receiving instrument, properly protected, to be lying there at the bottom in connection with the cable. Now, it is plain that this receiver will be influenced in the usual way by a Marconi transmitter aboard the cruiser, for the Hertzian waves pass well enough through water. With this arrangement, the captain of your cruiser may now converse freely with the admiral of the fleet at Key West or with the President himself at Washington, without so much as quitting his deck. He may report every movement of the Spanish warships as they take place, even while he is following them or being pursued by them. So long as he keeps within twenty or thirty miles of the submerged cable-end, he may continue his communications, may tell of arrivals and departures, of sorties, of loading transports, of filling bunkers with coal, and a hundred other details of practical warfare. In short, this captain and his innocent looking cruiser may become a never-closing eye for the distant American fleet. And it needs but little thought to see how easily an enemy at such disadvantage may be taken unawares or be led into betraying important plans."

And here we may leave this fascinating subject, in the hope that we have seen clearly what already is, and with a half discernment of what is yet to be.

CONVEYANCE OF THOUGHT

Sound

By ELISHA GRAY

VIBRATION is an oscillation, or shaking to and fro, made by a stationary body (like a pendulum, or a stretched wire) when disturbed from its equilibrium or rest. When this motion is slow—as a pendulum—it is called oscillation; when rapid—as of a wire or tuning-fork—it is called vibration. The latter term is used also in describing the action of a disturbed fluid—as of water, air, or ether—when it results in a wave-motion, a phenomenon so familiar that it needs no definition. The effects of Sound, Light, and Heat are all produced through vibrations of the medium transmitting the disturbing force. We will begin with the first named.

Sound is one of the important mediums through which the inner man communicates with the outer world. It may be defined as Motion or Vibration, in its objective or outer manifestations, and as Sensation in its effect upon our consciousness through the medium of the organs of hearing.

There are many avenues to the brain that are in touch with the outer world through the medium of the five senses. Through all of these avenues the same general vehicle is used to carry intelligence to the brain of the percipient—to wit, motion.

It is motion of the optic nerve that carries to the brain the sensation of light. It is motion of the gustatory nerve that carries to the brain the sensation of taste. It is motion of the olfactory nerve that carries to the brain the sensation of smell. It is motion of the nerves of feeling that carries the sense of

touch; and it is a motion of the auditory nerve that gives us the sensation of sound.

Nothing but sound can be transmitted through the auditory nerve, and nothing but light through the optic nerve. The same is true of the other avenues to the brain: you cannot smell with your tongue or taste with your nose, although the sense of taste and smell are very closely allied; that is, we often taste and smell at the same time, but attribute the sensation all to taste. Put a cinnamon drop on your tongue and hold your nose and you will taste only sugar. You get the taste of cinnamon only when the nasal passages are open. We really taste and smell at the same time, in some instances, and call it all taste. Each special nerve has its special use. If we have lost one of these highways between the outer world and the inner self, by so much we are dead to physical things.

All the phenomena of sound, outside of the point where we perceive it, are simply motions of some character. The different kinds of sound are infinite, but each sensation of sound that differs from another has its correlative in the air outside of the ear as a peculiar form of motion. For instance, if some one out of sight, but not out of hearing, should sound a note on a violin, you would say that you heard a violin; but if some one should sound a note, of the same pitch, on an organ, you would say that you heard an organ. What is the difference? Simply that the kind or quality of the motion made by the violin differs from that of the organ; hence the difference of the sensation. What this difference is will be fully explained in its proper place.

Let us now go back and follow out the course of a single sound-impulse from its source to the ear, and through it to the brain—the seat of sensation.

Let us fill a soap-bubble with oxygen and hydrogen gases in the proportion of two parts of hydrogen to one of oxygen. If we ignite it the result will be an explosion. When the ignition takes place there is a sudden generation of heat, which suddenly expands the air, causing it to be highly rarefied at the point of explosion. The air immediately surrounding it is driven violently outward in every direction. The first layer of

air-particles, surrounding the bubble, is driven against the second and then swings back to its place, for the force that drove it outward is no longer present. The second layer swings against the third and the third against the fourth, and so on; each layer after making its excursion outward returns to its original position. The air-particles are not fired at the ear as from a gun; they simply vibrate to and fro. The sound-pulse moves outward like an expanding globe at the rate of about 1,100 feet per second in air, the speed depending upon the medium through which it travels.

Some notion of the movement of a sound-pulsation may be had by watching the expanding ring made by a pebble when dropped into a pond of smooth water. A still clearer idea may be had by laying a number of billiard-balls in a groove, so that they are in close contact. Now tap on one of the end balls sharply and watch the effect. None of the balls seem to have changed position except the end one, opposite from the one that received the blow. This one has rolled away from the others. The first ball struck delivered its blow to the second, and so on to the last. This one, having nothing to deliver its blow to, rolls away under the impetus given to it by the ball next to it. This is precisely what takes place in the air, only with balls infinitely small, as compared with the billiard-balls. Each ball has made a pendulous motion; it has moved forward a short space and returned to its original position. The distance it has moved forward and back is called the amplitude (largeness—size) of its motion or vibration, and, other things being equal, the loudness of a sound varies as the square of the amplitude of the vibratory impulse.

Starting again with our soap-bubble, from the point of explosion: the same impulse moves in every direction—like light from a single luminous point—through the air, but produces no sensation till it strikes an ear. The membrane of the ear is made to vibrate or swing back and forth, which, in turn, moves the inner mechanism of the ear—for it is a mechanism, and a most wonderful one—which finally communicates its motion to the auditory nerve, which reaches into the brain, where the motion is translated into a sensation that we call

Sound. What is this mysterious blending between the activities of the outer world and the sense-perception of the inner consciousness? All the combined wisdom of philosophers and sages has never solved the problem. Much has been written, but no explanation, only words, words, words. We have to be satisfied with studying the phenomena only, of natural law, for that is all we can really know about it. We perceive the facts, but cannot explain how the physical is translated into mental consciousness.

Sound is transmitted either through gases, liquids, or solids, but the velocity is determined by the elasticity of the medium through which it is transmitted. Numerous experiments have been made to determine the velocity of sound when transmitted through different media, and long tables on this subject may be found. The following table will give a general idea of the velocity of sound through solids, liquids, and gases:

The velocity through air, 1,100 feet per second.
The velocity through water, over four times that of air.
The velocity through pine wood, ten times that of air.
The velocity through iron, seventeen times that of air.

These figures are only approximately correct, as the velocity of sound in gases varies with changes of temperature. Again, a loud sound travels faster than a feeble one. A striking instance of this fact is shown in an experiment made by some Arctic explorers. Sounds, even moderate ones, are heard to comparatively great distances over smooth ice. A cannon was fired, and the observer, who was quite a distance from the gun, heard the boom of the cannon before he heard the order to fire, which of course, was given first.

Sound cannot be transmitted through a vacuum, as shown by the following familiar experiment made by a philosopher named Hawksbee as far back as 1705. Place a bell that is operated by a clockwork inside of the receiver of an air-pump. This receiver is a large bell-glass, ground to make an air-tight fit on the bedplate of the air-pump. Suspend the bell inside the receiver, by some kind of cord that will not transmit sound, and then set it to ringing. At first it will ring as loudly as

though it were in the open air. Now, work the pump and exhaust the air. The sound will grow fainter until a nearly perfect vacuum is obtained, when the sound will cease, although the hammer is still striking the bell the same as at first. Now let the air in and the ringing is heard again.

Reasoning from the above experiment, one should expect that sounds would not be as loud on high mountains as down on the sea-level. This is found to be the case, because the air at very high elevations is much less dense and there are fewer air molecules in a given area to strike upon the drum of the ear.

For the same reason sound will be carried farther and seem louder on some days than others. When the barometer is high it shows that the air is dense, and dense air is a better medium for sound transmission than rarefied air, at least so far as loudness is concerned. The experiment with the bell in a vacuum shows that sound is transmitted only through material of some kind that may be made manifest to our senses. It also shows that matter, as we understand it, is not necessary for the transmission of light and radiant heat, for both light and radiant heat will pass through the vacuum, when the bell will not sound, as readily as through the air.

Sound is reflected like light. It may be focused on a single point, like light or radiant heat, by means of concave reflectors. It tends to move in straight lines, but will in a degree go around an object; yet a large object casts a distinct sound-shadow, if we may use the term. If we throw an elastic ball on the floor with considerable force it will rebound at the same angle at which it was moving when it struck the floor. The direction it was moving before it struck is called the angle of incidence, and the direction it moves after that is called the angle of reflection. Sound and light obey this law. Sound waves are reflected from a polished surface the same as light waves, and they obey the same laws in the matter of focusing and dispersion that light does.

A striking instance of sound reflection may be noticed any time during the passage of a thunderstorm. Whoever has stood on a mountain top towering 15,000 feet above the sea and from this view-point of a cloudless sky and bright sunshine has

looked down upon a storm-cloud hovering far below against the side of the mountain, and stretching far across the valley, has witnessed a scene of grandeur that no language can adequately describe. It is from a view like this that one gets an accurate conception of cloud-form as it really is. Great billowy mountains, whose crests are tipped with purest silver and whose shapes are as multiformed as the leaves of the forest and as numberless as the sands of the desert!

A storm-cloud as seen from above, under the full rays of the sun, appears to be, and doubtless is, made up of a series of clouds that may or may not touch each other. During the progress of the storm one or more of the clouds becomes surcharged from time to time with electricity, when it seeks to establish an equilibrium, by discharging into the earth or into another cloud. This discharge causes a great sound wave to flow out from the point of disruption, much louder than the booming of the heaviest cannon, and it travels, as we have seen, at the rate of 1,100 feet per second through the air in all directions. Suppose we are standing one mile from the point of disruption in the cloud, watching the operation of nature's great electrical power-plant. We see a flash of lightning, and in a little less than five seconds we hear the thunder; and, although there has been only a single report like the firing of a cannon, it seems to us to be a great many following each other in rapid succession. We have already seen that a sound wave moves out like an expanding globe from a common center, which is the origin of the sound impulse. A part of the wave coming from the cloud moves in a direct line toward the observer. When the wave strikes his ear there is the sensation of an explosion of great power, and this is followed by others in rapid succession, for several seconds, each succeeding one growing weaker until it dies out in what seems to be a distant roll of thunder. The explanation is this: Beyond the cloud where the discharge took place, and farther away from the observer, is another cloud with a large reflecting surface, and beyond that a second, a third, and so on, it may be, for many miles. Each one of these surfaces reflects back to the ear of the observer a part of this great sonorous impulse; but as a

part of the wave that is reflected, is reflected from the successive cloud surfaces that are farther away, and no two of them the same, the reflected sound keeps on coming to the ear at disjointed intervals, because the distances are constantly increasing and not uniform. If the first cloud beyond the point of explosion is five hundred and fifty feet farther away from the observer, the second explosion, or the first reflected explosion, will occur one second after the first; for it has to travel five hundred and fifty feet away, and then retrace the distance. So, by that time, the original wave will have one-fifth of a mile the start. This is the cause in many instances, and the chief cause in most cases, of the phenomena of rolling thunder.

CONVEYANCE OF THOUGHT

How the Telephone Talks

By ELISHA GRAY

EVERYBODY knows what the telephone is, because it is in almost every man's house. But while everybody knows what it is, there are very few (comparatively speaking) who know how it works.

When any one utters a spoken word, the air is thrown into shivers or vibrations of a peculiar form, and every different sound has a different form. Therefore, every articulate word differs from every other word, not only as a shape in the air, but as a sensation in the brain, where the air vibrations have been conducted through the organ of hearing; otherwise we could not distinguish between one word and another. Every different word produces a different sensation because there is a physical difference, as a shape or motion, in the air where it is uttered. If one word contains 1,000 simultaneous air motions and another 1,500, you can see that there is a physical or mechanical difference in the air.

The construction of the simplest form of telephone is as follows: Take a piece of iron rod one-half or three-quarters of an inch long and one-quarter inch thick, and after putting a spool-head on each end to hold the wire in place, wind it full of fine insulated copper wire; fasten the end of this spool to the end of a straight-bar permanent magnet. Then put the whole into a suitable frame, and mount a thin circular diaphragm (membrane or plate) of iron or steel, held by its edges, so that the free end of the spool will come near to but not touch the center of the diaphragm. This diaphragm must be held rigidly at the edges.

Now if the two ends of the insulated copper wires are brought out to suitable binding-screws, the instrument is done.

The permanent steel magnet serves a double purpose. When the telephone was first used commercially, the instrument now used as a receiver was also used as a transmitter. As a transmitter it is a dynamo-electric machine. Every time the iron diaphragm is moved in the magnetic field of the pole of the permanent magnet, which in this case is the free end of the spool (the iron of the spool being magnetic by contact with the permanent magnet), there is a current set up in the wire wound on the spool; a short impulse, lasting only as long as the movements lasts. The intensity of the impulse will depend upon the amplitude and quickness of the movement of the diaphragm. If there is a long movement there will be a strong current, and vice versa. If a sound is uttered, and even if the multitude of sounds that are required to form a word, be spoken to the diaphragm, the latter partakes in kind of the air motions that strike it. It swings or vibrates in the air, and if it is a perfect diaphragm it moves exactly as the air does, both as to amplitude and complexity of movement.

All these complex motions are communicated by the air to the diaphragm, and the diaphragm sets up electric currents in the wire wound on the spool, corresponding exactly in number and form, so that the current is molded exactly as the air waves are. Now, if we connect another telephone in the circuit, and talk to one of them, the diaphragm of the other will be vibrated by the electric current sent, and caused to move in sympathy with it and make exactly the same motions relatively, both as to number and amplitude.

It will be plain that if the receiving diaphragm is making the same motions as the transmitting diaphragm, it will put the air in the same kind of motion that the air is in at the transmitting end, and will produce the same sensation when sensed by the brain through the ear. If the air motion is that of any spoken word, it will be the same at both ends of the line, except that it will not be so intense at the receiving end; it is the same relatively. And this is how the telephone talks.

I have said that the permanent magnet had two functions.

In the case of the transmitter it is the medium through which mechanical is converted into electrical energy. It corresponds to the field magnet of the dynamo, while the diaphragm corresponds to the revolving armature, and the voice is the steam engine that drives it. In the second place, it puts a tension on the diaphragm and also puts the molecules of the iron core of the magnet in a state of tension or magnetic strain, and in that condition both the molecules and the diaphragm are much more sensitive to the electric impulses sent over the wire from the transmitter. At the present day this form of telephone is used only as a receiver.

Transmitters have been made in a variety of forms, but there are only two generic methods of transmission. One is the magneto method—the one we have described—and the other is effected by varying the resistance of a battery current. The former will work without a battery, as the voice acting on the wire around the magnet through the diaphragm creates the current; in the latter the current is created by the battery but molded by the voice. In the latter method the current passes through carbon contacts that are moved by the diaphragm. Carbon is the best substance, because it will bear a wider separation of contact without actually breaking the current. When carbon points are separated that have an electric current passing through them, there is an arc formed on the same principle as the electric arc-light.

Great improvements in details have been made in the telephone since its first use, but no new principles have been discovered as applied to transmission.

We have spoken in another place regarding the various claimants to the invention of the telephone, but here is one that has been overlooked. A young man from the country was in a telegraph office at one time and was left alone while the operator went to dinner. Suddenly the sounder started up and rattled away at such a rate that the countryman thought something should be done. He leaned down close to the instrument and shouted as loudly as possible these words: "The operator has gone to dinner." From what we know now of the operation of the telephone I have no doubt but that he

transmitted his voice to some extent over the wire. This young man's claims have never been put forward before, and we are doing him tardy justice. But his claim is quite as good as many others set forth by people who think they invent, whenever it occurs to them that something new might possibly be done, if only somebody would do it. And when that somebody does do it, they lay claim to it.

In the early days of the telephone it was not supposed that a vocal message could be transmitted to a very great distance. However, as time went on and experiments were multiplied, the distance to which one could converse with another through a wire kept on increasing.

In these days, as every one knows, it is a daily occurrence that business men converse with each other, telephonically, for a distance of 1,000 miles or more; in fact, it is possible to transmit the voice through a single circuit about as great a distance as it is possible to practically telegraph. This leads us to speak of another telegraphic apparatus which we have not heretofore mentioned, and that is the telegraphic repeater. It is a common notion that messages are sent through a single circuit across the continent, but this is not the case, although the circuits are very much longer than they were some years ago. The repeater is an instrument that repeats a message automatically from one circuit to another. For instance, if Chicago is sending a message to New York through two circuits, the division being in Buffalo, the repeater will be located at Buffalo and under the control of both the operator at Chicago and the operator in New York. When Chicago is sending, one part of the repeater works in unison with the Chicago key and is the key to the New York circuit, which begins at Buffalo. When New York is sending, the other part of the repeater operates, which becomes a key which repeats the message to the Chicago line. In this way the practical result is the same as though the circuit were complete from New York to Chicago. At the present day some of the copper wires and perhaps some of the larger iron wires are used direct from Chicago to New York without repetition; but all messages between New York and San Francisco are automatically re-

peated at least twice, and under certain conditions of weather oftener.

The repeater was a very delicate instrument and had to be handled by a skilled operator. Every wire must be in its place, or the instrument would fail to operate. I remember on one occasion in Cleveland that along in the middle of the night the repeater failed to work. The operator knew nothing of the principle of its operation, so that when it failed he had to appeal to some of his superiors.

At this time there was no one in the office who knew how to adjust it, so they had to send up to the house of the superintendent and arouse him from his sleep and bring him down to the office. He looked under the table and found that one of the wires had loosened from its binding-post and was hanging down. He said immediately, "Here's the trouble; I should think you could have seen it yourself." The operator replied, "I did see that, but I didn't think one wire would make any difference." He learned the lesson that all electricians have had to learn—that even one wire makes all the difference in the world. But this operator was no worse in that respect than some of his superiors. One of the heads of the Cleveland office at one time in the early days wanted to give some directions to the office at Buffalo. He told the operator at the key to tell Buffalo so and so, when the operator replied: "I can't do it; Buffalo has his key open." The official immediately said with severity: "Tell him to close it." He forgot that it would be as difficult for him to tell him to close it, as it would have been to have sent the original message.

But let us go back to the telephone. While it is possible to send a message from New York to San Francisco by telegraph, it is not possible to telephone that distance, because as yet no one has been able to devise a repeater that will transfer spoken words from one line to another satisfactorily. But unless the printer and publisher bestir themselves, some one may accomplish the feat before this little book reaches the reader. If this proves to be true, let the writer be the first to congratulate the successful inventor.

LABOR-SAVING MACHINERY

The Wonder-Working Wheel

By ALFRED RUSSEL WALLACE

THE invention and partial development of much of our modern machinery dates from the last century, and our most advanced appliances for the manufacture of the various textile fabrics and hardware are mostly improvements of, or developments from, the older machines. These, taken in connection with the great improvements in steam engines, have multiplied many times over the efficiency of human labor, but do not otherwise specially interest us here. There are, however, a few inventions which have the character of quite new departures, since not only do they greatly diminish labor but they perform, by mechanical contrivances, operations which had been supposed to be beyond the power of machinery to execute. The more prominent of these are the sewing machine, the typewriter, and the combined reaping, threshing, and winnowing machine, of which a brief account will be given.

The sewing machine, now so common, exercised the ingenuity of mechanicians for a long period before it arrived at sufficient perfection to be suitable for general use. The earlier machines were for embroidering only; then, about 1790, one was made for stitching shoes, and other leather work, but it does not seem to have come into general use. A crocheting machine was patented in 1834; somewhat later one for rough basting; but it was not till 1846 that the first effective lock-stitch sewing machine was made by Elias Howe, of Cambridge, Mass. Henceforth sewing machines were rapidly improved and adapted to every variety of work; but the difficulty of the problem to

be solved is shown by the unusually long process of gradual development, much of the mechanical talent of both hemispheres being occupied for nearly a century before the various machines so familiar to-day were perfected. There are now special machines for making button-holes and for sewing on buttons, for carpet-sewing, for pattern-sewing, for leather work, and for the special operations required in the making and repairing of shoes. Boot and shoe-making by machinery, in large factories, has entirely grown up since the sewing machine was proved to be adapted for almost every kind of sewing work. As a result, machine-made boots and shoes are very cheap, but they are usually of inferior quality to the old hand-made articles; and first-class work is quite as dear as it was fifty or sixty years ago, or even dearer.

The typewriter is a still later invention, and though perhaps less difficult than the sewing machine, yet it involves more complex motions and adjustments, so that the perfection it has so quickly attained is very remarkable. If we consider that about sixty separate types, including small letters, capitals, spaces, stops, etc., have to be so arranged and so connected as to be brought in any order whatever to a definite position, so as to form the successive letters and spaces in lines of printed characters, and then, being properly inked, must be brought into contact with the paper so as to produce a clear impression, and that all the motions of the machinery required must be the result of a single pressure on a key for each letter, following one another as rapidly as possible, we shall have some idea of the difficulties which have had to be overcome. Yet, so great are the resources of modern mechanism, and the ingenuity of our mechanists, that the required result has been attained in many different ways, so that we may now choose between half a dozen forms of typewriters, no one of which seems to be very markedly superior to the rest.

More important, perhaps, to mankind generally, are the harvesting machines, which render it possible to utilize one or two fine days to secure a harvest. Reaping machines have long been used in this country, and they were followed by combined reapers and binders, which left the crop ready for carting

to the barn. But this, when the distance was great, did not save the grain from injury by wet, besides requiring much labor and a careful process of stacking to preserve it. In America a harvesting machine has been brought to perfection, which not only reaps the grain, but threshes it, winnows it, and delivers it into sacks ready for the granary or the market, at one operation. This machine, with two men, will, in one fine day, secure the crop from ten or fifteen acres, with a minimum of labor. In the great wheat fields of California and Australia, with an almost uniformly dry climate at harvest time, it is this saving of labor which is the chief consideration; but in our treacherous climate, where a few days' delay may mean the partial or complete ruin of the crop, such machines will be doubly valuable by enabling farmers to utilize to the utmost every fine day after the grain is ripe. I had the pleasure of seeing this wonderful machine at work in California in 1887. It was propelled by sixteen small mules harnessed behind, so as not to be in the way; but steam power is now used. Considering what it effected, it was wonderfully light, compact, and simple; and when agriculture is treated as a work of national importance, such machines will render us, to a considerable extent, independent of the weather, and will therefore become a necessity.

The three mechanical inventions here briefly described were conceived in the first half, and brought to perfection in the second half of the century. They each mark a new departure in human industry, inasmuch as they effect, by means of machinery and at one operation, what had previously been performed by human labor directed by a hand or arm rendered skillful by long practice, and sometimes requiring several distinct operations. They had been thus performed during the whole preceding period of human history, or so long as the particular kind of work had been done; so that, though of less general use and of less importance, they have the same distinguishing features which we have found to characterize our new methods of locomotion.

There are, of course, innumerable other remarkable mechanical inventions of the century in almost every department of in-

dustry—such as the Jacquard loom for pattern-weaving, revolvers and machine guns, iron ships, screw propellers, etc.; while machinery has been extensively applied to watch-making, screw-cutting, nail-making, printing, and a hundred other purposes. But none of these are of very high importance in themselves, or possess the special characteristics of being new and quite distinct departures from what has been done before, and they cannot therefore rank individually among those greater discoveries which preëminently distinguish the nineteenth century.

LABOR-SAVING MACHINERY

Printing, Past and Present

By JOHN TIMBS

THE inquirers into the origin and history of this almost ubiquitous "noble craft and mystery," would seem to have arrived at this conclusion—that it is difficult to say at what period of time the art of printing did not exist. The simplest and most natural mode of conveying an idea is by the reproduction of similar appearances of the same surface; and whether this be by a hand or foot upon snow, or by the pressure of wood or metal upon paper or vellum, it is alike printing. Accordingly, we find evidence that nearly four thousand years since, a rude and imperfect method was certainly practiced. First, seals were impressed upon a plastic material; next, symbols or characters were stamped upon clay in forming bricks (as practiced in Babylon), cylinders, and the walls of edifices. Of this art, Wilkinson and others have brought examples from Egypt; and Rawlinson and Layard from the ruins of the buried cities of Asia. Not only have the inscribed bricks been found, but the wooden stamps with which they were impressed; of these, numerous specimens are in the British Museum. Here also may be seen several instruments presenting a singular instance how very nearly we may approach to an important discovery, and yet miss it. These are brass or bronze stamps, having on their faces inscriptions in raised characters reversed. To the back has been fastened a handle, a loop, a boss, or a ring. One use of these stamps has evidently been to print the inscription, by aid of color, upon papyrus, linen, or parchment; and, as the inscriptions show these stamps to have been of the

period when literature had become one of the pursuits of the great, and the copying of books was a slow and expensive process, it is strange that the Romans, by whom these signets were used, should not have improved upon them by engraving whole sentences and compositions upon blocks, and thence transferring them to paper. The Chinese printing from blocks at this day closely resembles the old Roman; and they assert that it was used by them several centuries before it was known in Europe—in fact, fifty years before the Christian era.

A vast interval elapses between the above attempts and the next advance—engraving pictures upon wooden blocks, invented toward the end of the thirteenth century by a twin brother and sister of the illustrious family of Cunio, lords of Italy: these consisted of nine engravings of the "Heroic Actions" of Alexander the Great, and, as stated in the title-page, "first reduced, imagined, and attempted to be executed in relief, with a small knife, on blocks of wood"; "all this was done and finished by us when only sixteen years of age." This title, if genuine, presents us at once with the origin, execution, and design of the first attempts at block printing. The next earliest evidence is a decree found among the archives of the Company of Printers at Venice, dated 1441, relating to playing cards, printed from wood blocks, the impressions being taken by means of a burnisher. Then, instead of a single block a series of blocks was employed, in engravings of the *Biblia Pauperum*, the text being printed from movable types.

We have now reached the practice of printing, in the present sense of the term. The invention of the movable types is disputed by many cities, but only three have the slightest claim—Haarlem, Strasburg, and Mentz: Haarlem for Lawrence Koster, who, when "walking in a suburban grove, began first to fashion beech bark into letters, which being impressed upon paper, reversed in the manner of a seal, produced one verse, then another, as his fancy pleased, to be for copies for the children of his son-in-law." Next, he, with his son-in-law, devised "a more glutinous and tenacious species of writing ink, which he had commonly used to draw letters; thence he expressed entire figured pictures, with characters

added," only on opposite pages, not printed on both sides. Afterward he changed beech blocks for lead, and then for tin. The tradition adds that an unfaithful servant, having fled with the secret, set up for himself at Strasburg or Mentz; but the whole story, which claims the substitution of movable for fixed letters as early as 1430, cannot be traced beyond the middle of the sixteenth century, and is generally discredited as a romantic fiction. Nevertheless some have believed that a book called *Speculum Humanæ Salvationis*, of very rude wooden characters, proceeded from the Haarlem press before any other that is generally recognized. Whether movable wooden characters were ever employed in any entire work is very questionable; they appear, however, in the capital letters of some early printed books. "But," says Hallam, "no expedient of this kind could have fulfilled the great purposes of this invention, until it was perfected by founding metal types in a matrix or mould; the essential characteristic of printing, as distinguished from other arts that bear some analogy to it."

The invention is now unhesitatingly ascribed to John Gutenberg, a native of Mentz; the evidence of which does not rest upon guesses from dateless woodcuts, but upon a legal document, dated 1439, by which it is proved that Gutenberg, being engaged "in a wonderful and unknown art," admitted certain persons into partnership, one of whom dying, his brother claimed to be admitted as his successor; and on Gutenberg's refusal, they brought an action against him as principal partner. From the evidence produced in the trial, it was proved that one of the witnesses had been instructed by Gutenberg to "take the *stücke* (pages) from the presses, and, by removing two screws, thoroughly separate them from one another, so that no man may know what it is." From this curious document (says the latest investigator of the subject) may be learnt that separate types were used; for if they were block, arranged so as to print four pages (as stated in the evidence), how could they be so pulled to pieces that no one should know what they were, or how could the abstraction of two screws cause them to fall to pieces? We are here reminded that within comparatively few years screws have been substituted for quoins, or

GUTENBERG, THE INVENTOR OF PRINTING

wedges, in locking up the type in the chases, or iron frames; which may be a revival of Gutenberg's screw method of four hundred years since.

It seems that some sort of presses were now used, and the transfers no longer taken by a burnisher or roller; and lastly, that the art was still a great secret at the time when Koster was at the point of death. Hence it is manifest that the ingenuity of Gutenberg had made a vast advance from the rude methods of the time, and had in fact invented a new and hitherto unknown art.

All this took place at Strasburg, where Gutenberg resided many years; but it did not lead to any practical result, and the first book was printed at Mentz, near which the inventor was born. Thither Gutenberg returned about the year 1450, with all his materials. His former partnership had expired, and at Mentz he associated himself with John Fust, a wealthy goldsmith and citizen, who, upon agreement of being taught the secrets of the art, and admitted into the participation of the profits, advanced the necessary funds, 2,020 florins. The new partnership then hired a house called *Zum Jungen*, and took into their employ Peter Schœffer and others. A law suit arose between the partners in 1455; and from a document in existence we learn that, having expended the whole of his considerable private fortune in his experiments, Gutenberg had mortgaged his printing materials to Fust, which is proved by the initial letters used by Gutenberg and his partners in printing works between 1450 and 1455, being likewise used by Fust and Schœffer in the Psalter of 1457 and 1459. Gutenberg did not, however, abandon the unprofitable pursuit, but starting anew at Mentz, carried on the business for ten years; but in 1465, on becoming one of the band of gentleman pensioners of the Elector Adolphus of Nassau, "he finally abandoned the pursuit of an art, which, though it caused him infinite trouble and vexation, has been more effectual in preserving his name and the memory of his acts than all the warlike deeds and great achievetments of his renowned master and all his house" (Hansard) Gutenberg died on the 24th day of February, 1468. His printing office and materials were eventually sold to Nicholas

Bechtermunze of Elfield, whose works are greatly sought after by the curious, as they afford much proof, by collation, of the genuineness of the works attributed to his great predecessor.

It is hard to apportion the share of honor to which each of the partners—Gutenberg, Fust, and Schœffer—is entitled in advancing their art. Gutenberg would readily suggest a new and expeditious method of manufacturing types; the practical skill of Fust as a worker in metals, and his large pecuniary resources, would provide the necessary appliances; and the entire conception and execution of the casting of type is given to Schœffer. The only evidence shows that the partners had for some time taken casts of types in molds of plaster; for the types of Gutenberg's earlier efforts, both at Strasburg and at Mentz, were cut out of single pieces of wood or metal with infinite labor and imperfection. Schœffer has therefore an undoubted claim to be considered as one of the three inventors of printing; for it was he who first suggested the cutting of punches, whereby beautiful forms could be stamped upon the matrix, and the highest sharpness and finish given to the face. Lambinet, who thinks "the essence of the art of printing is in the engraved punch," naturally gives the chief credit to Schœffer; this is not the generally received opinion; but he is entitled to a place on the right hand of Gutenberg. It should be noted, that there is no book known which bears the conjoint names of Gutenberg, Fust, and Schœffer, nor any which has the imprint of Gutenberg alone; but there are several books which, from internal evidence, are unanimously attributed by the *literati* of all parties and opinions to Gutenberg's press.

It is curious to observe that war was the means of quickening the growth and extension of printing. In 1462, the storming of Mentz dispersed the workmen, and gave the secret to the world. In 1465, it appeared in Italy; in 1469, in France; in 1474, Caxton brought it to England; and in 1477, it was introduced into Spain.

It is generally believed that William Caxton was born in the Weald of Kent. About 1412 he was put apprentice to a mercer or merchant of London, became a traveling agent or factor in the Low Countries, and there bought manuscripts

and books, with other merchandise. He there also learned the new art of printing; and, securing one of Fust and Schœffer's fugitive workmen from Mentz, he established a printing office at Cologne, and there printed the French original and his own translation of the *Recuyell of the Historyes of Troy*. He afterward transferred his materials to England, and brought over with him Wynkyn de Worde, who probably was the first superintendent of Caxton's printing establishment. He set up his first press at Westminster, perhaps in one of the chapels attached to the Abbey, and certainly under the protection of the abbot; and he there produced the first book printed in England, *The Game of Chesse*, completed on the last day of March, 1474. His "capital work" was a *Book of the Noble Historyes of Kyng Arthur*, the most beautiful production of his press. He died in 1491, being about fourscore years of age. His industry and devotedness are recorded in the fact that he finished his translation of the *Vitæ Patrum*, from French into English, on the last day of his life.

Caxton was buried in the old church of St. Margaret, built in the reign of Edward I., and of which few traces remain. The parish books contain an entry of the expense "for iiij torches" and "the belle" at the old printer's "bureying"; and the same books record the churchwardens' selling for 6*s*. 8*d*. one of the books bequeathed to the church by Caxton! In the chancel a tablet to his memory was raised in 1820 by the Roxburghe Club.

A few words about the first presses. Gutenberg is thought to have felt the want of a machine of sufficient power to take the impressions of the types or blocks which he employed; nor is it supposed that, with cutting type, forming screws, making and inventing ink, he could have had time to construct a press, even had he possessed the requisite mechanical skill. His junction with Fust and Schœffer is thought to have supplied the defect.

The earliest form of printing press very closely resembled the common screw press, as the cheese or napkin press, with some contrivance for running the form of types, when inked under the pressure (obtained from the screw by means of a

lever inserted into the spindle), and back again when the pressure is made. The presses used in the office of Fust and Schœffer are believed to have differed in no essential form from the above, until improved in the details by Blew, a printer of Amsterdam, in 1620. Other improvements were from time to time introduced; but they were all superseded about the commencement of the present century, when the old wooden press gave way to Earl Stanhope's invention of the iron press which bears his name. Its novelty consisted in an improved application of the power to the spindle and screw, whereby it was greatly increased. Lord Stanhope also made some improvements in the process of stereotyping, and in the construction of locks for canals; he invented an ingenious machine for performing arithmetical operations; during a great part of his life he studied the action of the electric fluid; and in 1779 he made public his theory of what is called "the returning stroke of lightning." Lord Stanhope bequeathed £500 to the Royal Society, of which he had been a fellow fifty-one years.

The principle of the Stanhope press has been followed out by several subsequent inventors; and improvements of mechanical detail introduced, tending to the economy of time and labor, and to precision of workmanship. The printing press, however, proved inadequate to a rate of production equal to the demand; and as early as 1790, even before the Stanhope press was generally known, Mr. W. Nicholson patented a printing machine, of which the chief points were the following: "The type, being rubbed or scraped narrower towards the bottom, was to be fixed upon a cylinder, in order, as it were, to radiate from the centre of it. This cylinder, with its type, was to revolve in gear with another cylinder covered with soft leather (the impression cylinder), and the type received its ink from another cylinder, to which the inking apparatus was applied. The paper was impressed by passing between the type and impression cylinders" (Hansard). Such was the first printing machine; it was never brought into use, although most of Nicholson's plans were, when modified, adopted by after-constructors.

König, a German, conceived nearly the same idea; and

meeting with the encouragement in England which he failed to receive on the Continent, constructed a printing machine for Mr. Walter; and on November 28, 1814, the readers of the "Times" were informed that they were then, for the first time, reading a newspaper printed by machinery driven by steam power, and working at the rate of 1,100 impressions per hour. In this machine the ordinary type was used, and laid upon a flat surface, the impression being given by the form passing under a cylinder of great size.

The later improvements in printing cannot be adequately described in brief. Every one knows something of the wonderful typesetting machines by which one operator, sitting before what looks like an enlarged typewriter, does the labor of five hand compositors. By tapping the keys he causes molten metal to come out in the form of a line of solid type, ready to be inked and printed from. Hence the name Linotype. One of the most recent developments of this principle is the Lanston Monotype machine, which is at work producing magazines and books. The inventor describes it thus:

"A perfect typesetting machine should take the place of the hand compositor, setting the type letter by letter in proper order at a maximum speed and with a minimum chance of error. The Lanston Monotype machine solves this problem marvelously. To one who has seen the slow work of hand typesetting as the compositor builds up a long column of metal piece by piece, letter by letter, picking up each character from its allotted space in the font, and placing it in its proper order and position, and then realizes that much of the printed matter he sees is so produced, the wonder is how anything is ever accomplished.

In a quarto page of good-sized type there are about 7,000 separate pieces (not including spaces) of type, which, if set by hand, would have to be taken one by one and placed in the compositor's "stick," then when the line is nearly set it would have to be spaced out or justified to fill out the line exactly. Then when the compositor's "stick" is full, or two and a half inches have been set, the type has to be taken out and placed in a long channel or "galley." Each of these three operations

requires considerable time and close application, and with each change there is the possibility of error. It is a long, expensive process—a process in which the human equation is far too prominent. These three steps of hand composition, slow, expensive, open to many chances of mistake, have been covered at one stride at five times the speed, at one-third the cost, and much more accurately by the Monotype Machine.

A man sits at a keyboard, much like a typewriter in appearance, containing every character in common use (two hundred and twenty-five in all), and at a speed only limited by his dexterity he plays on the keys exactly as a typewriter works his machine. This is the sum total of human effort expended. The machine does all the rest of the work; furnishes the brains, and delivers the product in clean, shining new type, each piece perfect, each in its place, each line of exactly the right length, and each space between the words mathematically equal—absolutely "justified." It is practically hand composition with the human possibility of error, of weariness, of inattention, of ignorance, eliminated, all accomplished with a celerity that is astonishing.

The Lanston is a typecasting machine as well as typesetter. It casts the type (individual characters) it sets, perfect in face and body, capable of being used in hand composition or put to press directly from the machine and printed from. As each piece of type is separate, alterations are easily made—the corrected type, which the machine itself casts, is simply substituted for the defective matter, as in hand composition.

The machine is composed of two parts, the keyboard and the casting-setting machine. The keyboard part may be placed wherever convenient, away from noise or anything that is likely to distract or interrupt the operator, and the perforated roll of paper produced by it (which governs the setting machine) may be taken away as fast as it is finished. In the casting-setting machine is located the brains. The five-inch roll of paper perforated by the keyboard machine (a hole for every letter) gives the signal by means of compressed air to the mechanism that puts the matrix (or type mould) in position and casts the type letter by letter, each character following the proper sequence

as marked by the perforations of the paper ribbon. By means of an indicator scale on the keyboard the operator is informed how many spaces there are between the words of the line and the remaining space to be filled out to make the line the proper width. This information is marked on the paper ribbon by the pressure of two keys, and when the ribbon is transferred to the casting machine these space perforations so govern the casting that the line of type delivered at the "galley" complete shall be exactly the proper length and the spaces between the words be equal to the infinitesimal fraction of an inch.

LABOR–SAVING MACHINERY

Shoemaking Machines

By EARL MAYO

THE commonest things are the greatest mysteries. We search for the unknown and surprising to the uttermost parts of the earth, when, if we were wise enough to look there, we might find both under our very noses, or under our very feet.

To make good this statement in its most literal sense, take the shoe as an example. Certainly nothing is more common, more familiar, or more ubiquitous than the shoe. To provide the American people with footwear requires close to half a million pairs per day. There is no object more familiar to us all than a shoe, and yet of the mystery of its creation, of the marvelous ingenuity applied in its construction, not one man out of a hundred picked at random from the street could tell anything.

But there is no mystery about the making of a shoe, you say; and if pressed to the point, you may succeed in describing with fair exactitude the tedious operations of the leathern-aproned cobbler whom you used to pass each morning on your way to school, slowly pounding the leather to the shape of his last, punching with his awl, drawing his waxed ends through and through the leather, trimming with his queer-shaped knives. You have an idea that the methods of the old cobbler have been improved upon somewhat, but you do not realize that, measured by the march of industrial progress, he is as distant as the middle ages. It took the cobbler three days to make a pair of shoes. I have just visited a factory in Boston where 8,000 pairs of shoes are turned out every day by a force of

2,400 operators. This means three and one-half pairs for every man, woman, and child employed in the place. And yet not one of them possesses the skill of the vanished cobbler; not one of them could make a pair of shoes unaided by his fellows, and not more than two-thirds of them are employed directly in making shoes. The difference in the rate of production between the new workman and the old represents the share that machinery has come to play in the sphere of production. The results of the cobbler's experienced efforts have been multiplied by fifteen, and the multiplier is the complex machinery that inventive genius has supplied to do the work of human hands and brains—machines that almost think.

While these machines have increased enormously the possibilities of production, they have also complicated the methods by which these results are attained. It doubtless will surprise the average reader to be told that the shoes on his feet have passed through fully a hundred operations in their progress from the sheet of leather to the finished product; that there are fully this number of separate parts in every pair of shoes, and that some seventy or eighty hands have helped to shape them into what they are. But if he could view the transformation as it takes place thousands of times each day beneath the roof of every great shoe manufactory, if he could watch the leather assuming useful form as one intelligent piece of mechanism after another contributes its part toward the common result, he would be more astonished than he can be by any mere description.

To make thousands of highly specialized workmen and thousands of highly specialized machines work together in an economical, orderly, and profitable manner requires a thorough systematization. Thus every great shoe manufactory is so arranged that the raw material, starting at one end of the factory beneath the roof as a sheet of leather, emerges on the ground floor as a completed shoe ready to wear. To view the evolution of the shoe, therefore, let us mount together to the top of a big factory devoted to turning out a medium grade of shoes—shoes that can be purchased for three dollars or three dollars and a half per pair.

At the outset we encounter a mechanical wonder, a machine that knows arithmetic far better than we do, and that can perform instantaneously and easily a task that even a highly intelligent man could execute only slowly and tediously.

The leather comes into the factory in the form of pelts already tanned and prepared. These skins retain the same shape as when stripped from the calf or kid that they originally covered. Consequently they are irregular in form, having projections at the corners representing the part of the hide that came off the animal's legs. This leather is purchased by the square foot, and each pelt bears a mark indicating the number of square feet it contains. To measure each skin by the ordinary methods would be an impossible task, and yet, in a factory where thousands of them are used daily, it is in the highest degree important for the manufacturer to know whether or not he is receiving full measure.

To meet this requirement a very skillful machine has been devised. It is a primitive affair in appearance, consisting of a broad table, close to the surface of which are set a number of wheels placed close together on a horizontal axle on which they can revolve freely. Above the wheels, attached to the framework of the machine, are a series of balances arranged exactly as in an old-fashioned pair of scales, and surmounting the whole thing is a dial carrying an indicator marked off by figures, with spaces to show halves and quarters. Some odd-fangled weighing machine, one would say at first glance, but it is in reality a measuring machine instead.

Forming a part of each wheel and projecting from its side is a raised portion forming a segment of the circle represented by the wheel itself. Attached to one end of the arc of each segment is a wire chain extending over the pulleys carried on the arms of the balance. If the wheels are set in motion, their movement pulls downward on the chains, which in turn exert a pull on the arms of the balance; and the latter, being connected with the indicator of the dial, deflect it.

The space between the table and the set of wheels is just about wide enough for a sheet of paper to pass through. Set in the table to come exactly flush with its surface is a pair of

rolls which are set in motion whenever the machine is connected with the driving shaft that runs all the machinery in the room. If a pelt is placed on the table, these rolls carry it forward; it comes in contact with some of the set of wheels; the wheels turn, and their pull moves the indicator forward across the face of the dial.

Now the beauty of this mechanism is that its pulleys are so adjusted, in accordance with laws which every schoolboy learns in his study of physics, that the deflection of the indicator marks on the dial exactly the number of square feet in the surface of the side of leather that passes beneath the wheels. It matters not what the shape of the pelt may be, square, circular, or irregular, each part of it passes under some of the wheels on the axle, and causes them to move while it is passing beneath them and only them. Only a few seconds are required in the process, and the area of the leather is measured exactly to the fraction of a foot. Of course not all the pelts that come into the factory are measured; from each case that is opened a few are tested merely to verify the figures of the seller. If any discrepancy is found, the deficient pelts are not accepted.

The first step in the actual construction of the shoe is the cutting out of the leather and linings by patterns. There are separate patterns for each part, for each width and size, for each style; separate patterns for right and left shoes. A great amount of skill and art goes into the making of these patterns, and of the lasts on which the embryo shoes are placed later on in their careers. The chief pattern maker of a big concern frequently receives a salary of $5,000 or thereabouts. Many of the manufacturers buy their patterns and lasts ready made, and the manufacture of these is really a separate branch of the business.

In the cutting department we again confront the work of labor-saving machinery. A machine with a heavy beam, working exactly like a pile-driver, is cutting out linings, sending the sharp-edged steel form through thirty-two thicknesses of cloth at each blow. Rather more rapid that than cutting out each lining with a pair of shears, is it not? But the machine is of

the powerful, lumbering sort that lacks intelligence, and does not interest us particularly.

One point we need to observe here in the cutting-room in order to understand how it is that dozens of different parts entering into the construction of the shoe are kept from becoming hopelessly scattered. Attached to each bundle of parts as it is cut out is a long sheet covered with letters and figures which form the specifications for each pair of shoes, or rather for the number of pairs that are to be made from the one model at one time. The sheet is perforated so that it may be divided into three or four sections, but each section contains the same stamped number. Some part of this tag is attached to each of the parts of the shoe, so that, however widely separated the parts may become in their progress through the factory, they are brought together again at the proper time and place. The specification sheet serves another useful purpose. As each sheet contains a separate number, which is also stamped on the inside of the shoe, it is possible, by referring to this number, to trace the history of every pair of shoes back, even to the cutting-room, and through the hands of every operator who had a part in its production.

The processes of sewing together the different parts forming the upper and lining of the shoe and the making of buttonholes call for no particular description. They go on in what are known as the stitching-rooms, where hundreds of women, ranged before hundreds of sewing machines, are busily at work. Some of these machines present variations on familiar models, and perform tasks that are beyond the range of ordinary sewing machines.

By far the cleverest piece of mechanism in this department is the apparatus for stamping holes and putting in the eyelets through which the laces are to run. This machine has an arm extending out like the arm of a sewing machine. Along this arm is a grooved passage way leading from a hopper above the machine. The hopper is filled with blank forms of eyelets which are swept into the groove by a revolving brush. The perpendicular part of the machine's long arm is governed in its motion by a drive-wheel, and works like the needle-holder in a

sewing machine, except that, instead of a continuous motion, it is driven downward once for each revolution of the wheel.

A second arm, extending alongside and operated in the same way, carries a punch. When the shoe is placed in position and the machine is set in motion, the punch is driven downward, cutting a circular hole through the leather. At the next movement the shoe is carried forward, an eyelet fed out of the groove is caught by the point of the miniature pile-driver in its descent, is carried into the hole prepared for it, and neatly flattened out by the force of the blow, so that it is firmly pinned in position. By merely pressing a foot lever, the arm carrying the punching apparatus can be moved forward or backward, thus regulating the distance between the holes.

One of these machines will insert the eyelets in a case of shoes containing thirty-six pairs in fifteen minutes. This means something like eighty finished eyelets to the minute. The machine does in a quarter of an hour an amount of work that a skilled artisan could not accomplish in a day, and does it with a precision and regularity that the human workman could not equal. And the machine is operated by a young girl.

At this stage in its progress the various pieces forming the upper part of the shoe have been joined together. All the work has been done by machinery except the cutting out of certain parts from the patterns. Meanwhile, in another part of the factory the materials for the sole have been shaping. The thick outer covering and the thin inside part have been stamped out by forms placed beneath heavy beams operated as the one that we observed in the act of cutting out the linings. The inner sole has been shaped to the form that it occupies in the finished shoe by means of a heavy moulder operated by hydraulic power; at the same time a ridge has been raised up around the outer edge, to which a covering of canvas is attached by a stitching machine, thus adding greatly to its holding power.

The final step before the junction of the upper shoe and the sole is the sewing on of the welt, a strip of strong leather which serves to join the soft upper to the less flexible sole.

The welt is attached by means of a sewing machine directly after the shoe has gone through the process of lasting.

Here, at least, you will say, is a task before which machinery is helpless. To give a shoe the qualities requisite to a good fit, to keep it from drawing here and wrinkling there, it is necessary that the leather be drawn carefully over the wooden last which is placed inside the shoe, and fastened there with tacks to await the process of sewing. To become a competent laster requires skill and long experience, and the men who perform this work are always among the best paid in the factory. In many establishments the lasting is done by hand still, but there is a machine which will do the work and do it well, and this machine is utilized to a considerable extent in the making of the cheaper grade of shoes. It was named derisively the "nigger" laster by the workmen, because of the fact that its inventor was a mulatto; but no very long inspection is required to convince one of the fact that the machine is one entitled to respect.

A steel thumb and finger, working on a steel arm, grip the edge of the leather, and with the sideways pull characteristic of the hand laster bring the leather lightly over the edge of the last. At the end of the arm's pull, and just before the spring controlling the thumb and finger is released, a second arm descends with a sharp blow. This second arm is an automatic hammer. Short tacks are automatically fed along a narrow groove from a small hopper to a position directly beneath the hammer. The beauty of the apparatus is that it drives the nail only half way into the last, so that it may be pulled out easily when the sole is sewed on; a small circular guard below the hammer prevents the nail from being driven in for its full length. This mechanical laster works much more rapidly than any hand workman is capable of doing, and it performs a task that requires, in the case of the human workman, a combination of good judgment with mechanical exactitude.

The lasting is merely a preparatory step to the sewing of the shoe, which is done by another species of the remarkable sewing machines that are so much in evidence throughout the factory. The entire welt is sewed on in a fraction of a second,

instead of the half hour occupied by the laborious method of the old-time hand operator. A cutting machine, following the sewer, neatly trims off the edges.

The shoe is now ready to enter upon another stage of its construction—the affixing of the outer sole and heel; and we notice the fact that up to this point the light shoes for women have been put together inside out, although this is not the case with men's footwear.

The space between the inner and outer soles is filled with a substance the composition of which varies according to the notion of the manufacturer or the quality of the shoe. The most common is a mixture of ground cork and cement, which is useful in resisting damp, and at the same time assists the wearing quality of the shoe. When this has been done, the shoe is placed on a form beneath a heavy weight. The outer sole is covered with rubber cement laid in position, and pressed upon the shoe. The cement holds it in place temporarily until it can be sewed together by a machine that drives both needle and thread right through the heavy sole and affixes it firmly to the welt.

Next comes into play a very simple but extremely ingenious machine. The shoe is placed on another form, and a heavy roller, carrying a pressure of two tons, is run over the sole, forcing it down compactly upon the upper, and giving it the neatly rounded and finished appearance which the bottom of a new shoe presents. The arm carrying this roller moves backward and forward, and is so geared as to have also a rocking motion. Consequently the roller passes over every inch of the shoe's bottom surface, and its movements as it runs forward and backward, tilting from side to side, are remarkably humanlike, and suggest the presence of a brain hidden away somewhere in the machine and directing its operations.

When the sole has been put in place, the heel is affixed, and this is done by a machine suggestively named "the lightning nailer."

The various layers of leather comprising the heel have been pasted together in another part of the factory, or perhaps in another factory, for many of the shoemakers buy their heels

ready made. There remains only to fasten the heel to the shoe and to affix the bottom or outside heel-top, which is always put on separately. To do this is the work of the lightning nailer.

The machine is fed from a hopper into which the nails are poured and from which they are shaken down grooved inclines to fall into a form at the bottom. The form is exactly the shape of a shoe heel, and in it the nails are held upright in the position in which they are to be driven into the shoe. The heel is placed in position; the arm carrying the form, filled with upright nails, is carried horizontally about just above the heel; the valve that has held the nails from slipping out has been thrown aside by the release of a catch; a hammer descends and drives all the nails home at one blow, and contact with the iron form on which the shoe is placed clinches them on the inside. Along comes another arm, carrying the outside heel-top, over which a brushful of glue has been passed, and another smart blow fastens this in position, covering up the heads of the nails which hold the heel in place. Another machine, similar in operation, drives the row of nails which you may observe running along the outer edge of the heel of your shoe. These latter help hold the heel together to some extent, but they are put in chiefly for appearance' sake.

As soon as the outer edges of the sole and heel have been trimmed off smoothly by swiftly revolving circular knives, the shoe is practically complete. It is cleaned by revolving brushes; the sole is burnished on sandpaper and emery wheels; it is waxed by being held against a revolving wax-mould; the name and trademark of the maker is impressed by a mechanical stamp; the laces are inserted by girl operators; the shoe passes through the hands of an inspector, and thence it goes to the packing room, whence it emerges with thousands of others, packed in a neat cardboard box, ready for sale.

This rough description covers only the essential steps in the building of a shoe from a flat strip of leather into a form that will fit the human foot. There are dozens of minor operations, designed to add to the beauty or finish of the shoes, that have not been touched upon, and there are clever machines that perform nearly all these operations.

For example, if you look at the sole of a new shoe you will notice that the threads by which it is sewn do not show at all. Before the sole is sewed to the welt it receives the attention of a machine carrying a swiftly revolving, sharp little wheel that runs around its edge, turning up a thin layer of leather. After the sole is fastened on, this layer is turned down and pressed firmly by the heavy roller mentioned above. Similarly there is the "foxing" machine, which stamps out the rows of holes often seen along the edge of a box-tip or a vamp, and which give the shoe a finer appearance in the opinion of many buyers.

Another trick of the clumsy machinery that supplies us with footwear imitates the appearance of a hand-sewed sole. If you look on the top surface of the extension sole of a fashionable shoe you will notice a series of little grooves or cuts extending outward and separating the stitches by which the sole and welt are fastened together. The custom shoemaker cuts these little depressions so that his stitches will sink in even with the surface, and thus make his work less clumsy in appearance. The machine sewer draws these stitches as tight as it is possible for them to be, but, notwithstanding that they serve no practical purpose, the little grooves are added to improve the appearance of the shoe and to counterfeit the effect of hand-sewing.

If you watched the old cobbler carefully in the boyhood or girlhood days in which your ideas of shoemaking were formed, you may have noticed that whenever he sewed two pieces of leather together, he was accustomed to pound down the seam with his hammer to make it as flat as possible. The same thing is done in the modern factory, except that the pounding is done by an automatic hammer that strikes two hundred blows to the minute, and does the work in one-fiftieth of the time required by the man of the awl and leathern apron. In fact, inventive genius has succeeded in turning out machinery that performs rapidly and efficiently practically every operation that the most painstaking custom shoemaker of a generation ago put into his work.

LIGHT AND ITS USES

New Light on Light, or Revelations of Spectrum Analysis

By ALFRED RUSSEL WALLACE

HOW long ago it is since the use of fire, and some mode of producing it, enabled man to make the first advance toward civilization, we have no means of determining. As a matter of fact, the method of producing fire by friction is that most common among savages in all parts of the world; and since it requires only materials that are almost everywhere at hand, it descended even to some civilized peoples.

The more convenient method of striking a light by the use of flint, steel, and tinder, probably originated after iron was first made, and soon became adopted by all civilized people, and by many savages who possessed iron; and this method continued in use from the times of prehistoric man through all the ages of barbarism and civilization down to a century ago, and the process underwent hardly any improvement during that long period. One of the most vivid recollections of my childhood is of seeing the cook make tinder in the evening by burning old linen rags, and in the morning, with flint and steel obtaining the spark which, by careful blowing, spread sufficiently to ignite the thin brimstone match from which a candle was lit and fire secured for the day. The process was, however, sometimes, a tedious one, and if the tinder had accidentally got damp, or if the flint were worn out, after repeated failures a light had to be obtained from a neighbor. At that time there were few savages in any part of the world but could obtain fire as easily as the most civilized of mankind.

At length, after the use of these rude methods for many thousand years, a great discovery was made which revolutionized the process of fire-getting. The properties of phosphorus were known to the alchemists, and it is strange that its ready ignition by friction was not made use of to obtain fire at a much earlier period. It was, however, both an expensive and a dangerous material, and though about a hundred years ago it began to be made cheaply from bones, it was not used in the earliest friction matches. These were invented in 1827, or a little earlier, by John Walker, a chemist and druggist of Stockton-on-Tees, and consisted of wood splints, dipped in chlorate of potash and sulphur mixed with gum, which ignited when rubbed on sandpaper. Two years later the late Sir Isaac Holden invented a similar match. About 1834, phosphorus began to be used with the other materials to cause more easy ignition, and by 1840 these matches became so cheap as to come into general use in place of the old flint and steel. They have since spread to every part of the world, and their production constitutes one of the large manufacturing industries of England, Sweden, and many other countries.

Coming now to the use of fire as a light-giver, we find that an even greater change has taken place in our time. The first illuminants were probably torches made of resinous woods, which will give a flame for a considerable time. Then the resin exuding from many kinds of trees would be collected and applied to sticks or twigs, or to some fibrous materials tied up in bundles, such as are still used by many savage peoples, and were used in the old baronial halls. For out-door lights torches were used almost down to our times, an indication of which is seen in the iron torch extinguishers at the doors of many of the older West End houses; while, before the introduction of gas, link-boys were as common in the streets as match-sellers are now. Then came lamps, formed of small clay cups, holding some melted animal fat and a fibrous wick; and, somewhat later, rush-lights and candles. Still later, vegetable oils were used for lamps and wax candles; but the three modes of obtaining illumination for domestic purposes remained entirely unchanged in principle, and very little improved, throughout

the whole period of history down to the end of the eighteenth century. The Greek and Roman lamps, though in beautiful receptacles of bronze or silver, were exactly the same in principle as those of the lowest savage, and hardly better in light-giving power; and though various improvements in form were introduced, the first really important advance was made by the Argand burner. This introduced a current of air into the center of the flame as well as outside it, and, by means of a glass chimney, a regular supply of air was kept up, and a steady light produced. Although the invention was made at the end of the last century, the lamps were not sufficiently improved and cheapened to come into use till about 1830; and from that time onward many other improvements were made, chiefly dependent on the use of the cheap mineral oils, rendering lamps so inexpensive, and producing so good a light, that they are now found in the poorest cottages.

The only important improvement in candles is due to the use of paraffine fats instead of tallow, and of flat plaited wicks which are consumed by the flame. In my boyhood, the now extinct "snuffers" were in universal use, from the common rough iron article in the kitchen to elaborate polished steel spring-snuffers of various makes for the parlor, with pretty trays for them to stand in. Candles are still very largely used, being more portable and safer than most of the paraffine oil lamps. Even our lighthouses used only candles down to the early part of the present century.

A far more important and more radical change in our modes of illumination was the introduction of gas lighting. A few houses and factories were lighted with gas at the very end of the last century, but its first application to out-door or general purposes was in 1813, when Westminster Bridge was illuminated by it, and so successfully that its use rapidly spread to every town in the kingdom, for lighting private houses as well as streets and public buildings. When it was first proposed to light London with gas, Sir Humphrey Davy is said to have declared it to be impracticable, both on account of the enormous size of the needful gas-holders, and the great danger of explosions. These difficulties have, however, been overcome, as

was the supposed insuperable difficulty of carrying sufficient coal in the case of steamships crossing the Atlantic, the impossibilities of one generation becoming the realities of the next.

Still more recent, and more completely new in principle, is the electric light, which has already attained a considerable extension for public and private illumination, while it is applicable to many purposes unattainable by other kinds of light. Small incandescent lamps are now used for examinations of the larynx and in dentistry, and a lamp has even been introduced into the stomach by which the condition of that organ can be examined. For this last purpose numerous ingenious arrangements have to be made to prevent possible injury, and by means of prisms at the bends of the tube the operator can inspect the interior of the organ under a brilliant light. Other internal organs have been explored in a similar manner, and many new applications in this direction will no doubt be made. In illuminating submarine boats and exploring the interiors of sunken vessels it does what could hardly be effected by any other means.

The improvements in the mode of production of light for common use are sufficiently new and remarkable to distinguish this century from all the ages that preceded it, but they sink into insignificance when compared with the discoveries which have been made as to the nature of light itself, its effects on various kinds of matter leading to the art of photography, and the complex nature of the solar spectrum leading to spectrum analysis. This group of investigations alone is sufficient to distinguish the present century as an epoch of the most marvelous scientific discovery.

Although Huygens put forward the wave theory of light more than two hundred years ago, it was not accepted, or seriously studied, till the beginning of the present century, when it was revived by Thomas Young, and was shown by himself, by Fresnel, and other mathematicians, to explain all the phenomena of refraction, double refraction, polarization, diffraction, and interference, some of which were inexplicable to the Newtonian theory of the emission of material particles, which had previously been almost universally accepted. The complete establishment of the undulatory theory of light is a fact of the high-

est importance, and will take a very high place among the purely scientific discoveries of the century.

From a more practical point of view, however, nothing can surpass in interest and importance the discovery and continuous improvement of the photographic art, which has now reached such a development that there is hardly any science or any branch of intellectual study that is not indebted to it. A brief sketch of its origin and progress will therefore not be uninteresting.

The fact that certain salts of silver were darkened by exposure to sunlight was known to the alchemists in the sixteenth century, and this observation forms the rudiment from which the whole art has been developed. The application of this fact to the production of pictures belongs, however, wholly to our own time. In the year 1802, Wedgewood described a mode of copying paintings on glass by exposure to light, but neither he nor Sir Humphry Davy could find any means of rendering the copies permanent. This was first effected in 1814 by M. Niepce of Châlons, but no important results were obtained till 1839, when Daguerre perfected the beautiful process known as the daguerrotype. Permanent portraits were taken by him on silvered plates, and they were so delicate and beautiful that probably nothing in modern photography can surpass them. For several years they were the only portraits taken by the agency of light, but they were very costly, and were therefore completely superseded when cheaper methods were discovered.

About the same time a method was found for photographing leaves, lace, and other semi-transparent objects on paper, and rendering them permanent, but this was of comparatively little value. In the year 1850, the far superior collodion-film on glass was perfected, and negatives were taken in a camera-obscura, which, when placed on black velvet, or when coated with a black composition, produced pictures almost as perfect and beautiful as the daguerrotype itself, and at much less cost. Soon afterward positives were printed from the transparent negatives on suitably prepared paper, and thus was initiated the process, which, with endless modifications and improvements, is still in use. The main advance has been in the in-

creased sensitiveness of the photographic plates, so that, first, moving crowds, then breaking waves, running horses, and other quickly moving objects were taken, while now a bullet fired from a rifle can be photographed in the air.

With such marvelous powers, photography has come to the aid of the arts and sciences in ways which would have been perfectly inconceivable to our most learned men of a century ago. It furnishes the meteorologist, the physicist, and the biologist with self-registering instruments of extreme delicacy, and enables them to preserve accurate records of the most fleeting natural phenomena. By means of successive photographs at short intervals of time, we are able to study the motions of the wings of birds, and thus learn something of the mechanism of flight; while even the instantaneous lightning-flash can be depicted, and we thus learn, for the first time, the exact nature of its path.

Perhaps the most marvelous of all its achievements is in the field of astronomy. Every increase in the size and power of the telescope has revealed to us ever more and more stars in every part of the heavens; but, by the aid of photography, stars are shown which no telescope that has been, or that probably ever will be constructed, can render visible to the human eye. For by exposing the photographic plate in the focus of the object glass for some hours, almost infinitely faint stars impress their image, and the modern photographic star maps show us a surface densely packed with white points that seem almost as countless as the sands of the seashore. Yet every one of these points represents a star in its true relative position to the visible stars nearest to it, and thus gives at one operation an amount of accurate detail which could hardly be equaled by the labor of an astronomer for months or years—even if he could render all these stars visible, which, as we have seen, he cannot do. A photographic survey of the heavens is now in progress on one uniform system, which, when completed, will form a standard for future astronomers, and thus give to our successors some definite knowledge of the structure, and, perhaps, of the extent of the stellar universe.

It has long been the dream of photographers to discover

some mode of obtaining pictures which shall reproduce all the colors of nature without the intervention of the artist's manipulation. This was seen to be exceedingly difficult, if not impossible, because the chemical action of colored light has no power to produce pigments of the same color as the light itself, without which a photograph in natural colors would seem to be impossible. Nevertheless, the problem has been solved, but in a totally different manner; that is, by the principle of "interference," instead of by that of chemical action.

This principle was discovered by Newton, and is exemplified in the colors of the soap bubble, and in those of mother-of-pearl and other iridescent objects. It depends on the fact that the differently colored rays are of different wave lengths, and the waves reflected from two surfaces half a wave length apart neutralize each other and leave the remainder of the light colored. If, therefore, each differently colored ray of light can be made to produce a corresponding minute wave structure in a photographic film, then each part of the film will reflect only light of that particular wave length, and therefore of that particular color that produced it. This has actually been done by Professor Lippmann, of Paris, who published his method in 1891; and in a lecture before the Royal Society in April, 1896, he fully described it and exhibited many beautiful specimens.

The principle is the same for the light waves as that of the telephone for sound waves. The voice sets up vibrations in the transmitting diaphragm, which, by means of an electric current, are so exactly reproduced in the receiving diaphragm as to give out the same succession of sounds. An even more striking and, perhaps, closer analogy is that of the phonograph, where the vibrations of the diaphragm are permanently registered on a wax clyinder, which, at any future time, can be made to set up the same vibrations of the air, and thus reproduce the same succession of sounds, whether words or musical notes. So, the rays of every color and tint that fall upon the plate throw the deposited silver within the film into minute strata which permanently reflect light of the very same wave length, and therefore of the very same color as that which produced them.

The effects are said to be most beautiful, the only fault being that the colors are more brilliant than in nature, just as they are when viewed in the camera itself. This, however, may perhaps be remedied (if it requires remedying) by the use of a slightly opaque varnish. The comparatively little attention that has been given to this beautiful and scientifically perfect process is no doubt due to the fact that it is rather expensive, and that the pictures cannot, at present, be multiplied rapidly. But for that very reason it ought to be especially attractive to amateurs, who would have the pleasure of obtaining exquisite pictures which will not become commonplace by indefinite reproduction.

The brief sketch of the rise and progress of photography now given illustrates the same fact which we have already dwelt upon in the case of other discoveries. This beautiful and wonderful art, which already plays an important part in the daily life and enjoyment of all civilized people, and which has extended the bounds of human knowledge into the remotest depths of the starry universe, is not an improvement of, or development from, anything that went before it, but is a totally new departure. From that early period when the men of the stone age rudely outlined the mammoth and the reindeer on stone or ivory, the only means of representing men and animals, natural scenery, or the great events of human history, had been through the art of the painter or the sculptor. It is true that the highest Greek, or mediæval, or modern art, cannot be equaled by the productions of the photographic camera; but great artists are few and far between, and the ordinary or even the talented draughtsman can give us only suggestions of what he sees, so modified by his peculiar mannerism as often to result in a mere caricature of the truth. Should some historian in Japan study the characteristics of English ladies at two not remote epochs, as represented, say, by Frith and by Du Maurier, he would be driven to the conclusion that there had been a complete change of type, due to the introduction of some foreign race, in the interval between the works of these two artists. From such errors as this we shall be saved by photography; and our descendants in the middle of the coming

century will be able to see how much, and what kind, of change really does occur from age to age.

The importance of this is well seen by comparing any of the early works on ethnology, illustrated by portraits intended to represent the different "types of mankind," with recent volumes which give us copies of actual photographs of the same types; when we shall see how untrue to nature are the former, due probably to the artist having delineated those extreme forms, either of ugliness or of beauty, that most attracted his attention, and to his having exaggerated even these. Thus only can we account for the pictures in some old voyages showing an English sailor and a Patagonian as a dwarf beside a giant; and for the statement by the historian of Magellan's voyage, that their tallest sailor only came up to the waist of the first man they met. It is now known that the average height of Patagonian men is about five feet ten inches or five feet eleven inches, and none have been found to exceed six feet four inches. Photography would have saved us from such an error as this.

There will always be work for good artists, especially in the domain of color and of historical design; but the humblest photographer is now able to preserve for us, and for future generations, minutely accurate records of scenes in distant lands, of the ruins of ancient temples which are sometimes the only record of vanished races, and of animals or plants that are rapidly disappearing through the agency of man. And, what is still more important, they can preserve for us the forms and faces of the many lower races which are slowly but surely dying out before the rude incursions of our imperfect civilization.

Among the numerous scientific discoveries of our century we must give a very high, perhaps even the highest, place to spectrum analysis. Not only because it has completely solved the problem of the true nature and cause of the various spectra produced by different kinds of light, but because it has given us a perfectly new engine of research, by which we are enabled to penetrate into the remotest depths of space, and learn something of the constitution and the motions of the constituent bodies of the stellar universe. Through its means we

have acquired what are really the equivalents of new senses, which give us knowledge that before seemed absolutely and forever unattainable by man.

The solar spectrum is that colored band produced by allowing a sunbeam to pass through a prism, and a portion of it is given by the dewdrop or the crystal when the sun shines upon them; while the complete band is produced by the numerous raindrops, the colored rays from which form the rainbow. Newton examined the colors of the spectrum very carefully, and explained them on the theory that light of different colors has different refrangibilities—or, as we now say, different wave lengths. He also showed that a similar set of colors can be produced by the interference of rays when reflected from the two surfaces of very thin plates, as in the case of what are termed Newton's rings and in the iridescent colors of thin films of oil on water, of soap bubbles, and many other substances.

These color phenomena, although very interesting in themselves, and giving us more correct ideas of the nature of color in the objects around us, did not lead to anything further. But in 1802, the celebrated chemist, Dr. Wollaston, made the remarkable discovery that the solar spectrum, when closely examined, is crossed by very numerous black lines of various thicknesses, and at irregular distances from each other. Later, in 1817, these lines were carefully measured and mapped by Fraunhofer; but their meaning remained an unsolved problem till about the year 1860, when the German physicist, Kirchhoff, discovered the secret, and opened up to chemists and astronomers a new engine of research whose powers are probably not yet exhausted.

It was already known that the various chemical elements, when heated to incandescence, produce spectra consisting of a group of colored bands, and it had been noticed that some of these bands, as the yellow band of sodium, corresponded in position with certain black lines in the solar spectrum. Kirchhoff's discovery consisted in showing that, when the light from an incandescent body passes through the same substance in a state of vapor, much of it is absorbed, and the colored bands

become replaced by black lines. The black lines in the solar spectrum are due, on this theory, to the light from the incandescent body of the sun being partially absorbed in passing through the vapors which surround it. This theory led to a careful examination of the spectra of all the known elements, and on comparing them with the solar spectrum it was found that in many cases the colored bands of the elements corresponded exactly in position with certain groups of black lines in the solar spectrum. Thus hydrogen, sodium, iron, magnesium, copper, zinc, calcium, and many other elements have been proved to exist in the sun. Some outstanding solar lines, which did not correspond to any known terrestrial element, were supposed to indicate an element peculiar to the sun, which was therefore named helium. Quite recently this element has been discovered in a rare mineral, and its colored spectrum is found to correspond exactly to the dark lines in the solar spectrum on which it was founded, thus adding a final proof of the correctness of the theory, and affording a striking example of its value as an instrument of research.

The immediate effect of the application of the spectroscope to the stars was very striking. The supposition that they were suns became a certainty, since they gave spectra similar in character and often very closely resembling in detail that of our sun.

LIGHT AND ITS USES

Color

By ELISHA GRAY

IN the musical scale each note differs from the other in the matter of pitch; and pitch, as we have seen, is the rate of vibration per second. Colors differ in pitch the same as musical tones, and there are about an octave of them. If we allow a beam of sunlight to come into a dark room through a small aperture and let it fall on a white screen, there will appear a round spot of white light that is an image of the sun. If now we intercept the beam of light with a prism placed with the edge downward, there will appear on the screen a band of colors, one above the other. They will appear in the following order, beginning at the bottom: Red, orange, yellow, green, blue, indigo, violet, and the whole is called the solar spectrum. When a ray of light passes from a rarer to a denser medium—as from air through glass—the rays are bent out of their course, and the bend is different for each color. This bend is called refraction. The red ray is the least refracted and the violet the most; and this is why the violet appears at the top of the band of colors. This difference of bend in the color rays is due to the difference of wave length. For light, like sound, has a definite wave length for each vibration period. In order that we may better understand, let us go back a little and tabulate the vibration period of each color:

Red	477,000,000,000,000 per second
Orange	506,000,000,000,000 per second
Yellow	535,000,000,000,000 per second

Green	577,000,000,000,000	per second
Blue	622,000,000,000,000	per second
Indigo	658,000,000,000,000	per second
Violet	699,000,000,000,000	per second

It will be seen from the foregoing table that the vibration rate per second increases from red to violet. The wave length of the slowest vibration, to wit, red, is the greatest, the same as in sound, and the shortest is that of the most rapid—violet. The more waves there are in a given distance the greater the bend will be in passing from one medium to another.

The red ray has 39,000 waves to an inch, hence the wave length of red is one thirty-nine-thousandth of an inch. The violet ray has 57,000 waves to the inch. The red ray, having the fewest number of waves to the inch, is therefore bent out of its course the least, while the violet ray, having the greatest number per inch, is bent the most out of its course in passing through the prism. It will be seen from the foregoing why the colors are dispersed in passing through the prism.

It will be remembered that the wave length of a sound tone with 256 vibration periods per second was four feet and four inches in air. It will be noted that there is a vast difference between the wave length of a sound tone and that of a color tone.

You ask, why do different objects seem to have different colors? Color as a sensation is the effect of ether waves impinging upon the retina of the eye. When these waves enter the eye at the rate of 477,000,000,000,000 per second there is a sensation produced in the brain that we call red, but when the retina is agitated by 699,000,000,000,000 ether waves per second we experience the sensation of violet, and the same is true of the other colors; so that for each variation of rate within the limits of color there will be a corresponding variation of color sensation. Having now established the rates of motion and the wave lengths of the different colors of light, we are prepared to explain the phenomena of color as they appear on various objects that come within the range of our vision.

It has been stated in a preceding chapter that we see all non-luminous objects by reflected light. If a ray of white light

falls upon a black surface, all the colors are absorbed and none reflected. Darkness is the absence of light, hence we have black, which is simply the absence of all color. If a ray of light falls upon an object that absorbs all the colors but red, then red alone will be reflected to the eye and we have the sensation which belongs to that color, because the rate of vibration that produces this sensation of red is the only one that is reflected. This same thing would be true of all the colors. If an object has a violet color it is because all the other colors are absorbed and violet only is reflected to the eye, hence the sensation of violet.

When a color is absorbed it becomes heat. If we wear dark clothing the sun will seem much hotter than when we are clothed in white. The former absorbs the color vibrations, which become heat, while the latter reflects them. If we have some color tint which arises from a mixture of colors, it is because the object so tinted is able to reflect two or more color vibrations, the resultant of which is the tint. Colors, like sounds, may be mixed in an infinite number of proportions, and each change of proportion is not only a change of the physical conditions of the ether between the reflecting substance and the eye, but a change of sensation, or emotion. The blending of color motion affects our emotional nature somewhat as the blending of sonorous tones does. They may be harmonious and pleasing, or they may be inharmonious and irritating. Women are as a rule more sensitive to color tints than men, because their training has been such as to make them so. We hear them say, "Those colors fight," which is another way of saying that they are inharmonious and grate upon their sensitive nerves.

Color art is not yet developed so that it is a language of the emotions in the same sense that music is. Not long ago it could have been said that music was not an art. It may be that at some future time the art of color, so crudely developed now, will be brought to the same state of perfection as a language for the expression of emotion that the art of music has reached at the present time.

It will be impossible to give you more than a very few fun-

damental facts relating to this beautiful science, because so many of the phenomena, to be understood intelligently, need the aid of experiment and illustration that cannot be had here. The fundamental thought running through all the phenomena of sound, heat, and light, as well as electricity, is motion; motion, as related to our sense perceptions, and motion as related to all the innumerable phenomena of nature.

Let us now continue our investigation of color, from the standpoint of definite rates of motion and definite lengths of impulse. Every schoolboy is familiar with soap bubbles, and has spent many a happy hour blowing them. But he did not realize how many scientific truths could be extracted from them. The study of soap bubbles has led to some of the greatest discoveries.

The great Sir Isaac Newton made some of his most important discoveries by studying soap bubbles. Day after day he sat in his back yard blowing them and watching them rise in the air, displaying those varied hues of color that any one may see by trying the experiment. His neighbors became alarmed and took council among themselves as to what should be done for the "poor man." Poor, indeed, he was to those ignorant souls. But how rich was his life to the millions who have followed him!

For getting the finest results in the formation of soap bubbles, the best medium is a solution of castile soap and glycerine in the proportion of one part glycerine to two of the saturated solution of soap. First, take a common glass tumbler and dip the mouth of it into the solution, and by careful handling we can get a film of soap and glycerine stretched across the mouth of the tumbler. Now turn the tumbler over on its side and immediately bands of color will appear running across the film. You will notice that these colors change. We have already seen that every color has a definite wave length and a definite rate of vibration per second. A color will be reflected from the film when its thickness is one-fourth of the wave length that belongs to that color. We saw that when sound was reflected or reënforced by a hollow tube closed at one end, the tube was one-fourth the length of the sound wave. The same law holds good with color motion. The reflection is from the

back of the film, as sound is from the bottom of the tube. If the film is thick enough, the first color that will appear is red, and after that the others in the order of their succession in the solar spectrum. The film is constantly growing thinner at the top, by the stretching produced by gravity, and when it reaches the thickness of one one-hundred-and-fifty-six-thousandth of an inch the red ray will appear, as that is one-fourth the wave length of the red ray. When all the phases of color have appeared and passed down, there appears a patch of gray at the top of the film which tells us that it is stretched to its limit. And now it breaks. Knowing as we do the wave lengths of color, we are able to measure the thickness of the film. If violet has appeared on the film we know that it is not over one-fourth the thickness of a wave length of that color, which would be one two-hundred-and-twenty-eight-thousandth of an inch. This gives us also some idea of the size of a molecule of water, as the film cannot stretch to a thinness beyond the diameter of the molecule; although the film may break by its own weight long before its thickness has been reduced to that diameter.

Light waves may be made to interfere with each other the same as sound waves. If two sets of light waves of the same wave length are so related to each other that one set of waves falls in the depression between the other set, the result is darkness.

We have seen that if all the colors of a sunbeam are totally reflected to the eye from an object, the color of the object is white. But if some one of the colors is only partially reflected or entirely absorbed, the composite effect would be something away from white. There is an inconceivable number of variations and proportions of color, and as each variation may produce a variation of tone, or tint, we can see how all the delicate shadings of a poem or a symphony in color may be produced. Some time color and color tones may be classified and arranged in their order of succession and combination, and by some sort of instrument that will cause them to appear and disappear—played upon as we do upon a musical instrument to produce the effect of sound coloring. Color will then become a language of emotion, as music is now.

LIGHT AND ITS USES

The X-Rays

By JOHN TROWBRIDGE*

SINCE the publication of Hertz's paper on the penetration of thin sheets of metal, notably aluminum, by the cathode rays, interest in the remarkable phenomena investigated first by Professor Crookes has been reawakened to a marked degree; and most physicists during the past five years have regarded the subject of cathode rays as the most important one in electricity. In 1893 Lenard succeeded, by means of a Crookes tube provided with a small aluminum window, in detecting the cathode rays outside the tube in the air space of an ordinary room. He used paper disks covered with a very fluorescent substance, which became luminous when the cathode rays struck them; and he also succeeded in showing photographic effects of the rays. Now Röntgen, by the use of ordinary dry plates and without the use of an aluminum window, has taken photographs through wood and through the human hand by means of what he terms the *x*-rays, which he supposes are excited either in the glass walls of the Crookes tube or in the media outside the tube by means of the cathode rays.

We see, therefore, that the literature of the subject must be sought in the papers of Crookes, Hertz, Lenard, and Röntgen; and the interest in the mysterious manifestations of these invisible rays is twofold; first, in regard to the possible application of the phenomena to surgery, since the rays show a specific absorption, passing more easily through the flesh than through

* Rumford Professor at Harvard University.

bones or glass or metallic particles; and, secondly, in relation to the questions whether we are dealing here with radiant matter shot forth from the negative pole or cathode or with longitudinal waves of electricity.

Let us examine the possibility of the practical application of the cathode photography to surgery. The term cathode is applied to the zinc pole or negative pole of an ordinary battery. It is that terminal of an electrical machine which glows least in the dark when the machine is excited. It is the shortest carbon in the ordinary street electric lamp. The positive carbon or anode burns away twice as fast as the negative carbon or cathode. If the electric light is formed in a high vacuum by means of a great electro-motive force, we no longer have a voltaic arc or a spark; instead of this the exhausted vessel is filled with a feeble luminosity, and a beam of bluish rays is seen to stream from the negative terminal or cathode. When these rays strike the glass walls of the vessel they excite a strong fluorescence. If the glass contains an oxide of uranium, this fluorescence is yellow; if it contains an oxide of copper, it is green. Röntgen supposes that this fluorescence excited by the cathode rays is connected in some way with the formation of what he terms the *x*-rays. Now, a photograph of the bones in the hand, for instance, can be obtained by placing a sensitive plate in an ordinary photographic plate-holder. Resting the hand on the undrawn slide in the daylight, with the palm of the hand outward and toward the cathode, and about six inches away from it, the bones of the hand are thus brought in the nearest possible position to the sensitive plate. At the time of the present writing, the breast and the abdomen of the human body present too great thickness for successful photographs, and the attempts to obtain representations of the cavity in which the brain is situated have been failures, since the rays do not show any marked difference in fleshy tissues. Nothing can be obtained in these attempts to photograph the brain but a contour of the cavity in which it is situated, and possibly a shadowy representation of a bullet which might be imbedded in the head. The method of obtaining a successful photograph of the hand shows the present limitations of the method. In

order to obtain a fairly sharp shadow of a bone or of a shot, it should not be more than an inch away from the sensitive plate. The term shadow, however, is somewhat misleading. The photograph of the hand by the *x*-rays is entirely different from one produced by resting the hand in a similar position to that above described against an uncovered sensitive plate in a dark room and then lighting a match. By the last method we should obtain a true shadow of the hand, the flesh would throw as dense a shadow as the bones, and the latter could not be detected in the general blackness. In the cathode photograph, on the other hand, a difference in absorptive power is shown: the flesh looks like a hazy film around the skeleton, and even the medulla cavities can be made out, and the varying thickness of the bones is more or less shown. This specific absorption is of great scientific interest as well as of practical importance.

Now, these *x*-rays will penetrate several inches of wood, with varying amount of absorption, but they are almost entirely cut off by glass as thick as a window pane. They pass through thin layers of aluminum, even layers as thick as a silver ten-cent piece, while the silver coin almost entirely intercepts them.

It therefore immediately occurs to one, Why not return to Lenard's tube, provide a Crookes tube with an aluminum window, and thus save the great absorption of the glass walls of the tube? There are certain practical difficulties in the way. The aluminum must be very thin. Lenard used a window which was about one eight-thousandth of an inch thick, and it was necessarily very small, in order to stand the atmospheric pressure. An aluminum window one eighth of an inch thick, or as thick as a ten-cent piece, would absorb nearly as much as the glass walls of the present forms of Crookes tubes, which are not more than one sixtieth of an inch thick. Glass vessels seem at present to be more practical than any composite form, in which aluminum is glued to a glass-supporting vessel: first, because it can be blown very thin, and in a shape strong enough to withstand the atmospheric pressure; secondly, because the occluded air can be more effectively driven off the inner walls of the vessels by heating it while it is being ex-

hausted than it can be expelled from a vessel of any other material.

To obtain successful photographs, the exhaustion of the air must be pushed to a high degree; and this is also interesting from the scientific point of view. Moreover, a high electro-motive force is necessary. Pictures can be taken in less than one minute of the skeleton of the human hand by means of high vacua tubes excited by high electro-motive force. Even in this bare recital of the present limits of the application of the x-rays to photography, we perceive great possibilities in the application of the method to the surgery of the human extremities. There is no doubt that small foreign bodies, like shot and pieces of glass, can be detected in the fleshy tissues of the hand. Certain accessible regions of the body, like the mouth, can possibly be examined by placing a sensitive film inside the mouth and the cathode outside of the cheek; and it does not seem improbable that a suitable cathode vessel can be inserted into certain abdominal regions and a photograph be obtained by placing a sensitive plate on the outside of the body. By employing two cathodes, at the proper distance apart, stereoscopic representations of the bones can be obtained, and an estimate formed of the position of foreign bodies.

Let us now turn to some of the interesting scientific questions which have arisen in regard to this apparently new manifestation of the cathode rays. In the first place, they are apparently not refracted by paraffine, vulcanite, or wood, or by any substance which is penetrated by them. To test this, I employed a double-convex lens of wood and also a double-concave lens of the same material. I placed two copper rings in the concavity of the double-concave lens of wood, and also a similar copper ring outside the lens at the same height from the sensitive plate, as one of the rings which rested on the wood of the lens. I also placed a ring on the double-convex lens, and employed two cathodes to obtain two shadows from different positions. The thickness of the wooden lenses varied from half an inch to three quarters of an inch. The images obtained through the wood of the lenses were not distorted or changed in figure in any way by the wood, and therefore no

refraction could be observed by this method. On account of the quick diffusibility of the rays, no accurate method of determining a possible index of refraction seems possible. If the photographic effect is due to longitudinal waves in the ether, and if these waves travel with great velocity, no refraction would probably be observed. Maxwell's electro-magnetic theory of light supposes that only transverse waves are set up in the ether, and no longitudinal waves exist. On the other hand, Helmholtz's electro-magnetic theory of light postulates longitudinal waves as well as transverse waves. The longitudinal waves travel with an infinite velocity. Is it therefore possible that the x-waves are the longitudinal waves of Helmholtz's theory? Our apparent inability to refract the rays lends color to this hypothesis. Röntgen, in the preliminary account of his experiments, intimates that the phenomena may be due to longitudinal waves, and in a late article in the "Annalen der Physik und Chemie," by Jaumann, entitled "Longitudinal Light," Maxwell's electro-magnetic equations are modified so as to embrace the phenomenon of cathode rays; and the author shows that even Maxwell's theory can, under certain conditions, give a longitudinal wave.

The Röntgen phenomenon seems to be a manifestation of cathode rays brought to light and endowed with great practical interest by its application to dry-plate photography. When we return to the classical investigation of Lenard mentioned in the beginning of this article, we are impressed by an apparently crucial experiment which he describes in regard to the existence of an ether. He caused the cathode beam to pass out of his high vacua through an aluminum window into another tube about three feet long, which had been exhausted to such a high degree that no electrical discharge would pass through it. It seemed, therefore, to have an infinite electrical resistance. No cathode beam could be generated in it; nevertheless, by moving suitable disks of fluroescent matter from point to point in the tube by means of an outer magnet which attracted bits of iron on the disks, Lenard showed that the cathode beam passed through the vacuum. Energy passed into the vacuum and could be detected from point to point. We can conceive of

its passing through the ether in the tube by a wave motion, but not by a molecular movement, for there were no molecules to move. The molecular bombardment must have stopped at the aluminum window, and the resulting energy may have been propagated by ripples in the ether. This experiment of Lenard seems to me the most interesting one in the subject of cathode rays. The greatest mystery, however, which envelops the subject is the action of the x-rays on bodies charged with electricity. When the rays fall on, for instance, a charged pith ball, the charge disappears. A positive as well as a negative charge is dispelled by the x-rays. The energy of the medium about the pith ball is changed to a marked degree, and in this phenomenon we seem to be brought closer to a wave theory in a medium than to a molecular theory of movement of matter.

LIGHT AND ITS USES

X-Ray Photography

By RAY STANNARD BAKER

PERHAPS no inventor ever achieved world-wide distinction so quickly as Dr. William Konrad Röntgen. He discovered his famous *x*-rays on November 8, 1895; in December he described them before the Würzburg Physico-Medical Society; in January the marvel of the new rays which penetrate and photograph through almost every known substance was known all over the world, as well to newspaper readers as to the learned societies. A few months later many prominent scientists both in Europe and in America, were experimenting with Röntgen's rays, and within a year they had become a regular and exceedingly important factor in surgical operations. Moreover, no one disputed the originality of Dr. Röntgen's discovery; he had invented the first machine for photographing through solid substances, for taking pictures of the skeleton framework of the human body through the flesh. No one ever before had done that, and the scientific world was quick with its appreciation and liberal with its honors.

And yet this discovery, which many scientists rank side by side with Lister's system of antiseptics in its importance as a life saver, was not the result of happy chance. It was not mere luck. At the time that Dr. Röntgen saw the *x*-rays shimmering and glowing for the first time on a bit of sensitive paper he was past fifty years old, and during the greater part of his life he had been working quietly but industriously and thoughtfully with the great problems of physics and electricity. He laid the foundation of his career in a thorough education at

Zurich, his birthplace, and at Utrecht. Seven years before the discovery he had become a professor at the Royal University in the quaint old Bavarian town of Würzburg. Here, in a bare little laboratory in an equally modest two-story house, with few of the modern appliances, he made his famous experiments, and from here he went out, when the world heard of him, to receive the praise and decorations of his emperor. And after that he returned to his work, just as if he wasn't famous.

Dr. Röntgen (pronounced Rentgen) is a tall, slender, somewhat loosely built man, with a bushy beard and long hair rising straight up from a high white forehead. When he is excited or much in earnest he thrusts his fingers through this mass of hair until it bristles all over his head. He has an amiable face with kindly although penetrating eyes. His voice is full and deep, and he speaks with the rapidity of great enthusiasm. Indeed, his whole bearing tells of boundless energy and unremitting vigor. One visitor compared him on first sight to an amiable gust of wind.

Previous to the discovery which made him famous, Dr. Röntgen had actually been producing and working with *x*-rays for some time without knowing it. Indeed, other scientists had been doing much the same thing—experimenting all unconsciously on the very verge of the greatest discovery of years, but it remained for Dr. Röntgen, with his keener scientific insight, to see the unseen.

The famous electrician Hertz, whose discoveries have made possible more than one great invention, had tried sending a high-pressure electric current through a vacuum tube, a so-called Crookes tube. A vacuum tube is a vessel of very thin glass, having a platinum wire fixed in each end. This vessel is as nearly empty of everything as human ingenuity can make it; even the air is pumped out until only one one-millionth of an atmosphere remains. Hertz connected one of these tubes to the poles of his battery by means of the platinum wires. When the discharge began he observed that the anode—that is, the end of the tube connected with the positive pole of the battery—gave off certain peculiar and faint bands of light. But these were quite insignificant compared with the brilliant

and beautiful glow at the other or negative end of the tube, which is called the cathode. This glow resembled somewhat the fierce burning of an alcohol lamp, only it was softer, more evanescent, and more striking in its coloring. It produced brilliant phosphorescence in glass and many other substances, and Professor Lenard, Hertz's assistant, observed, in 1894, that the rays—"cathode rays," as they were called—would penetrate thin films of wood, aluminum, and other substances. But this was as far as any of the experimenters who preceded Röntgen succeeded in going.

Strangely enough, both Hertz and Lenard produced *x*-rays in abundance without knowing it. These were, indeed, present in the glow from the cathode, only they were entirely invisible to the human eye. They are different from the rays described by Lenard, in that they are not deflected—that is, turned aside—by a magnet, and they are incomparably more powerful in range and in penetrating power. It will be seen, therefore, that while Dr. Röntgen was not working in a wholly new field, his discovery is none the less entirely original.

The discovery itself was made in a peculiarly interesting way. Dr. Röntgen had been experimenting steadily for several weeks with his Crookes tubes. One day he had covered the tube with a light-excluding black shield. Then he had darkened his laboratory so that not a ray of light could anywhere enter. To the eye everything was absolutely black. When the electric current was turned on, the hooded tube did not show even a glint of light; but something on a shelf below began to glow, very strangely. It was a piece of sensitive paper—barium platino-cyanide paper. Dr. Röntgen knew that no light could come from the tube, because the shield that covered it was wholly impervious to light—even the strongest electric light. Where, then, did it come from? Dr. Röntgen began at once an eager investigation, moving the sensitive paper from side to side and covering the tube with a still denser screen. And finally he came to the conclusion that certain unknown rays, whether of light or not, he did not know, were actually coming through the screen, and giving the sensitive paper a distinct luminescence. It was contrary to all reason, to everything

that the text-books taught, and yet Dr. Röntgen was forced to believe it. And having discovered the existence of the new rays, he began at once to experiment with them. He found that they readily penetrated paper, wood, and cloth, and that the thickness of these mediums made little difference. That is, they would penetrate a thick book almost as easily as they would a single sheet of paper. Then he tried photographing, and found to his astonishment that the rays affected the sensitive film of the photographic plate, leaving the shadows of the objects exposed plainly outlined. For instance, he placed bits of platinum, aluminum, and brass inside of a wooden box, and found that not only did he get skiagraphs (shadowgraphs) of them through the wood, but all the nails that held the box together and the brass hinges were likewise reproduced. Then he photographed a spool of wire, the wooden ends of the spool leaving a very faint shadow, and the wire a dark one. When he tried glass, which is one of the most transparent of substances so far as ordinary light is concerned, he found that the new rays passed through it only with difficulty, and that aluminum was much more transparent to them than glass. In other words, if we lived in an *x*-ray world we might use aluminum for windows to let in the *x*-ray "light," and glass for shutters to keep it out.

After many experiments of this kind, it suddenly occurred to Dr. Röntgen that if the new rays penetrated all manner of substances, they would also penetrate the human body; that, in fact, they were probably going straight through his hands and his head as he worked with them. So he placed his hand, palm down, on a photographic plate, still in its black holder, arranged the Crookes tube above it, turned on the current, and in a short time he had a photograph, dim, it is true, but perfect, of the bony framework of his hand—the first of the kind ever taken, and a marvel up to that time absolutely inconceivable.

A little later he built a closet of tin just big enough to accommodate one man comfortably, and fitted it up with an aluminum window. Outside of the window he placed his new apparatus. Only the new rays would, of course, shine through

the aluminum, and he could study them at his leisure. But after long and careful experimenting he could not decide what the new rays really were, and although many theories have been advanced by prominent scientists, a really satisfactory explanation is still wanting. It is pretty generally believed, however, that Röntgen's rays are only a "mode of motion" through the ether—that is, they are produced by a certain peculiar kind of vibration in the ether. Dr. Röntgen himself gave them the name "*x*-rays"—the unknown rays.

But if the exact nature of the rays was a mystery, their uses and importance became familiar almost immediately. The apparatus was so simple that it could be fitted up in almost any laboratory. It consisted merely of a battery or dynamo current; a coil, usually a Rhumkorff coil, for intensifying the current, and a Crookes tube, which might have any one of twenty odd shapes. As a result of this simplicity thousands of surgeons and scientists were able to prepare experimental apparatus, and some of the results in this country were excellent, especially in photographing the human skeleton.

Even Edison, the greatest of American inventors, took up the work with great enthusiasm, and he shortly invented a curious but simple device by means of which one may actually see the bones of the hand or foot through the flesh. He called it the fluoroscope. It is merely a wooden box, larger at one end than at the other, the smaller end being so constructed and padded with cloth that it will fit exactly over the eyes without admitting any light. The other end of the box is covered with a sheet of thin cardboard coated with a chemical compound which becomes fluorescent—that is, shines or glows—when placed in range of the *x*-rays. By holding this box between one's eyes and a Crookes tube, and placing one hand on the sensitive cardboard, the *x*-rays will readily pierce the flesh, and the dark shadow of the skeleton of the hand may be seen. In this way a doctor can tell quickly the location of a bullet or a needle in the hand or foot, for he is able to look through the flesh as if it were glass.

The Röntgen rays have been put to many marvelous uses, most of them connected with bone photography in surgery

cases. And, strangely enough, when a physician is ready to photograph a broken arm, for instance, to see if it is properly set, he never thinks of removing the splints or the bandages; he simply photographs through them. And that is the reason why such a photograph often shows pins and buckles. Frequently, in cases where the patient is very weak, the photograph is taken through the bed-clothes as well as through the bandages—it doesn't make the slightest difference to these wonderful rays. It takes from two minutes to more than an hour to get a good skiagraph, but the operation is no more painful, if we count out the necessity of keeping still, than having a snap-shot taken.

One of the earliest skiagraphs, showing the medical importance of the *x*-rays, was taken in England. A boy of nineteen had injured his little finger playing ball, so that it was bent at the last joint, and he could neither extend it nor bend it farther down. Any attempt to do so caused him sharp pain. Before the skiagraph was taken the doctors declared that the finger must be amputated. A skiagraph showed, however, that there was only a little bridge of bone uniting the last two joints, thereby preventing the proper flexing of the finger. As soon as this was known an anæsthetic was administered, and by the use of a little force this bridge of bone was snapped, and the finger saved. That was the first finger to the credit of Dr. Röntgen's discovery.

Since then the *x*-rays have been used constantly for finding bullets embedded in the flesh—*x*-ray machines are now taken to war with every civilized army—for finding needles that have been driven into the foot, for examining deformities of the bones, and, more recently, for photographing foreign bodies in the larynx and windpipe, and even in the stomach. Think of the sufferings caused by probing for bullets, shot, and needles in the flesh, all saved by an easily taken skiagraph!

An English woman came to a doctor saying that she was suffering tortures from her shoes, so that she found it difficult to walk, and she even wanted some of her toes amputated. A skiagraph showed exactly what the trouble was. She had been wearing shoes much too small for her, and the bones had be-

come woefully twisted and bent. One sight of the photograph convinced her that she must wear broad-soled shoes. In a somewhat similar case in Austria, the doctors found that the great toe of the patient was twice as large as it should be. They found by feeling that there were two bones instead of one, but they could not tell which was the normal bone and which the one to be removed. A skiagraph showed the whole condition instantly.

One of the strangest uses to which x-rays ever have been put was at the instance of a Philadelphia woman. She had been traveling in Egypt, and had brought home what she believed to be the hand of a mummy. But some of her friends told her how Egyptian curiosities are likely to be manufactured and sold to unsuspecting travelers as genuine relics. One friend, himself a great traveler, assured her that she had bought a mere mass of pitch, plaster of Paris, and refuse mummy-cloth, not a hand. For a long time there was no way of deciding the question, until at last the owner of the relic had an x-ray photograph taken. And lo and behold! there in the picture was the complete skeleton of the hand of some ancient Egyptian; the relic was genuine, after all.

Another curious and important use of x-rays is in determining genuine from imitation diamonds. A European scientist has made many tests in this field, and he finds that while the x-rays will penetrate the genuine diamond and leave almost no shadow in the photograph, the false ones are nearly opaque to the rays, and appear very dark in the photograph. This unusual new test may some time supersede all others.

A great many experiments have been made looking to the use of x-rays in curing diseases. Several prominent physicians assert that the new rays kill all germs—consumption, typhoid fever, diphtheria, and so on—and that by applying them properly to the diseased portion of the body a cure may be effected.

LIGHT AND ITS USES

The Eye as an Optical Instrument

By AUSTIN FLINT*

I HAVE often wondered whether the statement, occasionally made by physicists, that the human eye is not a perfect optical instrument, is an expression of human vanity or of an imperfect knowledge of the anatomy of the eye and the physiology of vision; and I have come to the conclusion that the latter is the more reasonable theory. The approach to perfection in modern telescopes and microscopes is wonderful indeed; but as physiologists have advanced the knowledge of vision, the so-called imperfections of the eye have been steadily disappearing; and even now there is much to learn. Viewed merely as an optical instrument, an apparatus contained in a globe less than an inch in diameter, in which is produced an image practically perfect in form and color, which can be accurately adjusted almost instantly for every distance from five inches to infinity, is movable in every direction, has an area for the detection of the most minute details and at the same time a sufficient appreciation of large objects, is double, but the images in either eye exactly coinciding, enables us to see all shades of color, estimate distance, solidity, and to some extent the consistence of objects, the normal human eye may well be called perfect. The more, indeed, the eye is studied in detail, the more thoroughly does one appreciate its perfection as an optical apparatus.

Were it not for a slight projection of the cornea (the trans-

* Professor of Physiology, Bellevue Hospital College, New York.

parent covering in front) the eye would have nearly the form of a perfect globe a small fraction less than an inch in diameter. It lies in a soft bed of fat, is held in place by little muscles and a ligament which is so lubricated that its movements take place with the minimum of friction. It is protected by an overhanging bony arch and the eyelids, the eyelashes keeping away dust, and the eyebrows directing away the sweat. Situated thus in the orbit, the eyes may be moved to the extent of about forty-five degrees; but beyond this it is necessary to move the head.

The accuracy of vision depends primarily upon the formation of a perfect image upon the retina, which is a membrane, sensitive to light, connected with the optic nerve. That such an image is actually formed has been demonstrated by an instrument, the ophthalmoscope, which enables us to look into the eye and see the image itself. Although the image is inverted, the brain takes no cognizance of this, and every object is appreciated in its actual position. The image is formed in the eye in the way in which an image is produced and thrown on a screen by a magic lantern.

When a ray of light passes obliquely from the air through glass, water, or other transparent media, it is bent, or refracted, and the angle at which it is bent is called the index of refraction. In passing to the retina, the rays of light pass through the cornea, a watery liquid (the aqueous humor) surrounding the lens, the crystalline lens, and a gelatinous liquid (the vitreous humor) filling the posterior two-thirds of the globe, all of which have the same index of refraction. This provides that a ray of light, having once passed through the cornea, is not refracted in passing through the other transparent media, except by the curvatures of the crystalline, which is a double-convex lens situated just behind the pupil. The rays of light are not reflected within the eye itself, for the opaque parts of the globe are lined with a black membrane (the choroid), as the tube of a microscope is blackened for a similar purpose. Practically, the bending of the rays of light is produced by the curved surface of the cornea and the two curved surfaces of the double-convex crystalline lens. These three curved surfaces bring the rays from an object to a focus exactly at the retina in a normal

eye. When, however, the eye is too long, the focus is in front of the retina unless, in near vision, the object be brought very near the eye, and the person is near-sighted. For ordinary vision, such persons must wear properly adjusted concave glasses to carry the focus farther back. When the eye is too short, the focus is behind the retina, and the person is far-sighted and must wear convex glasses. The first condition is called myopia, and the second, hypermetropia; but in most persons who are obliged to wear convex glasses in advanced life, the crystalline lens has become flattened and inelastic, the diameter of the eye being unaltered. This condition is called presbyopia, which means a defect in vision due to old age.

One of the wonderful things about the eye is the mechanism by which a perfect image is formed. What is called the area of distinct vision is a depression in the yellow spot of the retina, which is probably not more than a thirty-sixth of an inch in diameter. It is with this little spot that we examine minute details of objects. If we receive the rays of light from an object upon a double-convex lens and throw them upon a screen in a darkened room, the image of the object appears upon the screen; but in order to render this image even moderately distinct it is necessary to carefully adjust the lens, or the combination of lenses, to a certain distance, which is different for lenses of different curvatures. In the human eye the adjustment is most accurately made, almost instantaneously, for any desired distance, not by changing the distance between the crystalline lens and the retina, but by changing the curvature of the crystalline lens itself. The way in which this is done has been known only within the last few years. The lens is elastic, and in a quiescent or what is called an indolent condition, is compressed between the two layers of the ligament which holds it in place. In this condition, when the rays from distant objects are practically parallel as they strike the eye, the lens is adjusted for infinite distance. When, however, we examine a near object, by the action of a little muscle within the eyeball the ligament is relaxed and the elastic lens becomes more convex. This action is called accommodation, and is voluntary, though usually automatic. The fact that it is voluntary

is illustrated by the very simple experiment of looking at a distant object through a gauze placed a few feet from the eye. When we see the distant object distinctly, we do not see the gauze; but by an effort we can distinctly see the meshes of the gauze, and then the object becomes indistinct. In some old persons the lens not only becomes flattened, but it loses a great part of its elasticity and the power of accommodation is nearly lost.

The changes in the curvatures of the lens in accommodation have been actually measured. The lens itself is only about a third of an inch in diameter and its central portion is only a fourth of an inch thick. Adjusted for infinite distance, the front curvature has a radius of about four-tenths of an inch, while for near objects the radius is only about three-tenths of an inch. A curious experiment is looking at a minute object through a pinhole in a bit of paper or cardboard, when the object appears highly magnified. This is because the nearer the object is to the eye, the larger it appears. The shortest normal distance of distinct vision is about five inches; but in looking through a pinhole we can see at a distance of less than an inch, using a very small part of the central portion of the crystalline lens. Accommodation for very near objects is assisted, also, by contraction of a little band of fibers in the iris, about a fiftieth of an inch in width, immediately surrounding the pupil.

The most wonderful thing about the formation of a perfect image upon the retina is the mechanism of correction for form and color. In grinding lenses for the microscope, for example, it is mechanically easy to make a very small convex lens with perfectly regular curvatures—that is, each curvature being a portion of a perfect sphere; but in such a lens the focus of the central portion is longer than that of the parts near the edge; and when an object is in focus for the center it is out of focus for the periphery. This is a fatal objection to the use of uncorrected lenses of high power; but in microscopes it is corrected by combinations of lenses, reducing the magnifying power, however, about one-half. This is not all. When white light passes through a simple lens it is decomposed into the

colors of the spectrum. This is called dispersion, and it surrounds the object with a fringe of colors. The dispersion by concave lenses is exactly the opposite of the dispersion by convex lenses, so that this may be corrected by a combination of the two; but when this is done with lenses made of precisely the same material, the magnifying power is lost. Newton supposed that it was an impossibility to construct a lens corrected for color which would magnify objects; but since the discovery (in 1753 and 1757) of different kinds of glass having the same refractive power but widely different dispersive powers, perfect lenses have been possible.

In the human eye, a practically perfect image, with no alteration in color, is produced by a mechanism which human ingenuity cannot imitate. There is a slight error in the cornea, which is corrected by an opposite error in the crystalline lens; the iris plays the part of the diaphragm of optical instruments and shuts off the light from the borders of the crystalline lens, where the error is greatest, particularly in near vision; the curvatures of the lens are not perfectly spherical, but are such that the form of objects is not distorted; and while such curvatures are theoretically calculable, their construction is practically impossible, as experience has shown; different layers of the crystalline lens have different dispersive powers; and thus a practically perfect image, with no appreciable decomposition of white light, is formed on the retina.

Another wonderful thing about the eye, which adapts it most beautifully to our requirements, is the division of the sensitive parts of the retina into a very small area for distinct vision, which we use for reading, for example, and a large surrounding area in which vision is indistinct. If we saw with equal distinctness with all parts of the retina, the vision of minute objects would be confused and imperfect. As it is, the area of distinct vision is very small, probably less than one thirty-sixth of an inch in diameter. In this area, the distance between the separate sensitive elements is not more than one thirty-five-hundredth of an inch; while, if we pass from this only eight degrees, the distance is increased a hundred times. Still, in looking at any one object in the center of distinct

vision, the imperfect forms of surrounding objects are appreciated, warning us, perhaps, of the approach of danger.

The mechanism of distinct and indistinct vision has been understood only since 1876. The sensitive parts of the retina are little rods and cones forming a layer by themselves. In 1876, Boll discovered that in frogs kept in the dark the rods of the retina were colored a dark purple; but on exposure to light the color faded, becoming first yellow and then white. Since that time, physiologists have been carefully investigating visual purple and visual yellow. Just outside the layer of rods and cones are the dark cells which render the greatest part of the interior of the eye almost black. In the dark, these cells send little filaments between the rods and discharge a liquid which colors the rods alone. When the rods are thus colored, the eye is extremely sensitive, so that a bright light is dazzling and painful and obscures distinct vision. This is the reason why we cannot see distinctly when we come suddenly from the dark into a full light. In a few seconds, however, the color is bleached to a yellow and the difficulty passes away. When, on the other hand, we pass from a bright light into the dark, the retina has lost its sensibility from disappearance of the visual purple, and we cannot see at all until the purple is reproduced, as it is in the absence of light. This difference is not due to dilatation of the pupil in the dark and contraction under the influence of light, as is popularly supposed, for a person does not see better in the dark when the pupil has been fully dilated by belladonna.

In the little area of distinct vision there is never any visual purple. This area we always use with sufficient light for minute details of objects, making then the greatest use of the mechanism of accommodation. The area outside of this is used for indistinct vision, and as the color is then yellow instead of purple, it is only moderately sensitive. To express the conditions in a few words, the minute area for distinct vision is used by day, and the area for indistinct vision, with its visual purple, is used by night.

A very curious condition is what is known as night-blindness. Sometimes, in long tropical voyages, sailors become

affected with total blindness at night, while vision in the daytime is perfect. The glare of the sun in the long days bleaches the visual purple so completely that it cannot be restored in a single night, and the area of indistinct vision becomes insensible. This trouble is purely local and is remedied by rest of the eye. If one eye be protected by a bandage during the day, this eye will be restored sufficiently for the next night's watch, while the unprotected eye is as bad as ever. Snow-blindness in the arctic regions is due to the same cause.

We receive the impression of a single object, although there are two images—one in either eye; but it is necessary that the images be made upon corresponding points in the two retinæ. If the angle of vision in one eye be deviated even to a slight degree by pressing on one globe with the finger, we see two images. One can appreciate how exactly these points must correspond when it is remembered that two rays of light appear as one only when the distance between them is one thirty-five-hundredth of an inch.

In either eye there is a blind spot, and this is at the point of penetration of the optic nerve; but, inasmuch as this spot is in the area of indistinct vision, and is so situated—a little within the line of distinct vision—that an impression is never made on both blind spots by the same object, this blindness is never appreciable, and the spot can be detected only by the most careful investigation.

Not the least of the wonders of the eye are connected with the appreciation of images made upon the retina by certain parts of the brain. It is literally true that a person may see and yet not perceive. It has happened, in certain injuries of the brain, that a person sees and reads the words in a book and yet does not perceive their significance. This is called word-blindness. In a certain portion of the brain is a part which enables us to recognize the fact that we see an object; yet this object conveys no idea. There are two of these so-called centers of vision, one on either side, and their action is partly crossed. When the center is destroyed on one side, the inner half of one eye and the outer half of the other eye are blinded. Farther back in the brain, however, is a center which

enables us to perceive or understand what is seen. When this center is destroyed we see objects and may avoid obstacles in walking, but persons, words, etc., are not recognized. This center exists only on the left side of the brain.

An impression, however short, made upon the retina is perceived. The letters on a printed page are distinctly seen when illuminated by an electric spark, the duration of which is only forty billionths of a second; but the impression remains much longer. Anything in motion appears to us in a way quite different from the single impression that we should have from an electric spark. In a picture representing an animal in motion, as it appears in an instantaneous photograph, the positions seem absurd and like nothing we have ever seen. In looking at a horse in action, the impressions made by the different positions of the animal run into each other, and art should represent as nearly as possible the sum or average of these impressions. It is also true that impressions are diffused in the retina beyond the points upon which they are directly received. This is called irradiation; and the impression is diffused farther for white or light-colored than for black or dark objects. It is well known that a white square looks considerably larger than a dark square of exactly the same size; or the hands in white gloves look larger than in black gloves.

I have described, in as simple a way as possible, some wonderful things about the eye ascertained and explained by modern investigations; but there are many interesting facts ascertained which space has not permitted me to discuss, and there still remains much that is not yet understood. The whole question of the appreciation of colors and of color blindness is still wrapped in mystery. We know that some persons cannot distinguish between certain colors, but the reason of this is obscure. Perfect sight can exist only when the eye is perfect. The form and color of objects may be distorted so that an inaccurate image is formed upon the retina, and this image, however imperfect it may be, is what is perceived by the brain. In hearing, the case is different. The waves of sound, if they be conducted to the internal ear, and if the nerve of hearing, with its terminations, be normal, cannot be modified in course

of transmission. Sounds are always appreciated at their exact value, except as regards intensity. Enough has been said about the eye, I think, to show that it is perfectly adapted to all requirements, and whatever defects it may seem to have, viewed as an optical instrument, render it more useful to us than if these apparent defects did not exist.

ASTRONOMY

Discoveries in the Heavens

By ALFRED RUSSEL WALLACE

MANY of the most striking discoveries in this science have been already described under Spectrum Analysis; but there remain a few great advances, due either to observation or to theory, which are of sufficient popular interest to demand notice in any sketch, however brief, of the scientific progress of the century.

With the single exception of Uranus, discovered by Herschel in 1781, no addition had been made to the five planets known to the ancients till the commencement of the present century, when Ceres, the first of the minor planets, was discovered in 1801, and three others between that date and 1807. No more were found till one was added in 1845, and another in 1847. Since that time no year has passed without the detection of one or more new planets belonging to the same system, till in September, 1896, their number amounted to 417. These small bodies form a kind of planetary ring situated between Mars and Jupiter, where it had long been suspected a planet ought to be found, because the distance between these older planets was so great as to be quite out of proportion with the regular increase of distance maintained by the other members of the system. It was at first thought that these asteroids or minor planets were the shattered remains of a much larger one; but more extended knowledge of the constitution of the solar system renders it more probable that they really constitute a ring of matter thrown off by the sun during its progressive contraction; and that some peculiar conditions have prevented its vari-

ous parts from aggregating into a single planet. This is rendered more probable by two other remarkable discoveries relating to meteors and comets, and to Saturn's rings, which will be discussed later on.

The next large planet added to our system is especially interesting, as affording a striking demonstration of the theory of gravitation, and a no less striking example of the powers of modern mathematics. It had been found that the motions of Uranus were not exactly what they ought to be, if due solely to the attraction of the sun and the disturbing influence of Jupiter and Saturn, and it was thought possible that there might be another planet beyond it to cause these irregularities. In the year 1843 a young Cambridge student (John Couch Adams) of the highest mathematical ability, determined to see whether it was not possible to prove the existence of such a planet; and having taken his degree as senior wrangler, he at once devoted himself to the work, and after two years of study and calculation he was able to declare that a planet which would account for the perturbation of Uranus must, if it existed, be at that time in a certain part of the heavens, and he sent his paper on the subject to the Astronomer-Royal in October, 1845. By an extraordinary coincidence, a French astronomer (Leverrier) had been for some years working out the motions of the various planets, and in doing so had also reached the conclusion that there must be another unknown body to produce the perturbations of Uranus, which were at that time unusually large. His calculations and results were published at Paris in November, 1845, and June, 1846, and he gave a position for the unknown planet differing only one degree from that given by Adams. On reading these papers, and seeing the agreement of two independent workers, the Astronomer-Royal asked Professor Challis, of the Cambridge Observatory, to search for the planet, and on doing so he actually observed it on August 4th, and again on August 12th; but having no accurate chart of that part of the heavens he could not be sure that it was not a small star. A month later it was found and identified at Berlin, from information furnished by Leverrier It thus appears that Adams first privately announced the posi-

tion of the new planet, and that it was first observed at Cambridge; while the somewhat later announcement by Leverrier and discovery at Berlin were made public, and thus gained the honors of priority. The two discoveries were, however, practically simultaneous and independent, and the names of Adams and Leverrier should forever be jointly associated with the planet Neptune.

Other important discoveries in the planetary system are due to the increased power of modern telescopes and the greater number of observers. In 1877 two minute satellites of Mars were discovered at Washington, by means of the large telescope with a 25-inch object glass, then the largest in the world. These are remarkable in being exceedingly small, and very close to the planet. They are said to be only six or seven miles in diameter, and the inner one is only about 5,800 miles from the center, or 3,800 from the surface, of the planet, around which it revolves in less than eight hours; while the outer one is about 14,500 miles away, and revolves in a little more than thirty hours.*

Still more recently (in September, 1892), a fifth satellite of Jupiter was discovered by means of the great Lick telescope in California. This also is very small and very close to the planet, being less than half the diameter, or about 40,000 miles, from its surface.

Another very remarkable discovery is that of a system of symmetrical markings, covering a large part of the surface of Mars. They consist of a series of triangles or quadrilaterals bounded by straight lines, which are sometimes seen double, at other times single, or are even altogether invisible. Another peculiar feature is, that where these canals (as they are termed) intersect there is always a black circular spot, very distinct, and unlike any markings upon other parts of the surface. It is

---

* In "Gulliver's Travels," published in 1726, Swift describes the astronomers of Laputa as having "discovered two lesser stars, or satellities, which revolve around Mars; whereof the innermost is distant from the center of the primary planet exactly three of his diameters, and the outermost five; the former revolves in the space of ten hours, and the latter in twenty-one and a half." This is a wonderful anticipation, especially as to time of revolution, and if we substitute "radii" for "diameters," the distances are also very near.

a curious fact that the double canals sometimes enclose a space of more than a hundred miles wide and several hundred long, adding to the appearance of artificiality. Sometimes no canals are seen, but they come into view as the polar snows begin to melt; hence the suggestion that they really indicate great canals to carry off the water from the rapidly melting snow and distribute it by irrigation channels over the adjacent land, which, being rapidly covered with vegetation, causes the change of color which renders them visible. These observations were made by Mr. Percival Lowell during the favorable opposition, in 1894, at his observatory in Arizona, where the exceptional purity of the atmosphere renders it possible almost constantly to observe details which are elsewhere rarely visible. If future observations should confirm the views as to the artificial nature of these features of the surface of the planet which most nearly resembles our earth, it must be considered to be the most sensational astronomical discovery of the nineteenth century, and that which opens up the most exciting possibilities as to communication with beings who are sufficiently advanced to execute such widespread and gigantic irrigation works.

The ring around the planet Saturn was long supposed to be single, and to be solid like the planet itself; but with improved telescopes it was found to be double, and with still finer instruments to consist of an indefinite number of rings close together, one of them being very obscure, as if formed of nebulous matter. In the year 1859, Clerk-Maxwell, by a profound mathematical investigation, proved that either solid or liquid rings would be unstable, and would inevitably break up so as to form a number of satellites; and he concluded that the rings really consisted of a crowd of small bodies so near together as to appear like a solid mass; and as the appearance of the rings, and some slight changes detected in them, were in harmony with this view, it has been generally accepted. But quite recently the wonderful instrument, the spectroscope, has given the final demonstration that this theory is correct. If the rings are solid, it is clear that a point on the outer edge must move more rapidly than one on the inner edge; whereas, if they consist of separate particles, each revolving independently round

the planet, then, in accordance with the laws of all planetary motions, those forming the inner side of the rings, being nearer to the planet, must move much quicker than those on the outer side. As already explained, the spectroscope enables us to measure motion in the line of sight—that is, toward or away from us—of any heavenly bodies, and by observing the outer extremities of the rings to the right and left of the planet, where the motion is, of course, in these two directions, it is found that the motion of the inner edge is considerably more rapid than that of the outer edge, showing that those parts move round the planet independently, and are therefore formed of separate particles or small masses. These observations were made by the American astronomer, Professor James E. Keller, in 1895, and are of extreme delicacy; but that they are trustworthy is shown by the fact that the resulting velocities are in accordance with Kepler's third law, which determines the relative motions of all planetary bodies at varying distances from the primary.

A still more important discovery is that which has explained, by one consistent theory, the various phenomena presented by aërolites, fireballs, and shooting or falling stars, now generally classed as meteors and meteorites; and this theory is found to have an important bearing on the constitution of the solar system, and perhaps even on that of the whole stellar universe. Although there are records of the fall of solid stones from the sky in the works of classical, Chinese, and European authors, from 654 B. C. down to our times, while the astronomer Gassendi himself witnessed the fall of a stone weighing fifty-nine pounds in the year 1627, in the south of France, yet the phenomenon was so rare, and so inexplicable, that it was often disbelieved. One philosopher is reported to have disposed of the whole matter by saying, "There are no stones in the sky, therefore none can fall from it." But the evidence for such falls soon became overwhelming, and their connection with fireballs and shooting stars was also well established. One of the most remarkable of modern meteors was that seen at Aigle in Normandy, on April 26, 1803. About 1 P.M. a brilliant fire-ball was seen traversing the air at great speed. A violent ex-

RICHARD ANTHONY PROCTOR.

plosion followed, apparently proceeding from a small lofty cloud. This was no doubt the product of the explosion which would be visible long before the sound was heard, and then came a perfect shower of stones, nearly three thousand being picked up, the largest weighing eight pounds. A still more extraordinary meteor was seen on March 19, 1719, about eight o'clock in the evening, in all parts of England, Scotland, and Ireland. In London it appeared like a ball of fire as large as the moon; at Exeter the light was like that of the sun. It was followed by a broad stream of light, and burst with a report like that of a cannon, with a great display of red sparks like a huge sky-rocket; but as it was then over the sea, between Devonshire and the coast of Brittany, its fragments were not recoverable. Dr. Whiston, Newton's successor as professor of mathematics at Cambridge, who published an account of it, calculated its height over London as fifty-one miles, and over Devonshire thirty-nine miles.

ASTRONOMY

The Planet Mars

By SIR ROBERT BALL*

SEEING that the existence of intelligence is a characteristic feature of this earth, we feel naturally very much interested in the question as to whether there can be intelligent beings dwelling on other worlds around us. It is only regrettable that our means of solving this problem are so inadequate. Indeed, until quite lately it would have been almost futile to discuss this question at all. All that could then have been said on the subject amounted to little more than the statement that it would be intolerable presumption for man to suppose that he alone, of all beings in the universe, was endowed with intelligence, and that his insignificant little earth, alone amid the myriad globes of space, enjoyed the distinction of being the abode of life. Recent discovery has, however, given a new aspect to this question. At the end of the century certain observations were made disclosing features in the neighboring planet, Mars, which have riveted the attention of the world. On this question, above most others, extreme caution is necessary. It is especially the duty of the man of science to weigh carefully the evidence offered to him on a subject so important. He will test that evidence by every means in his power, and if he finds the evidence establishes certain conclusions, then he is bound to accept such conclusions irrespective of all other circumstances.

Mr. Percival Lowell has an observatory in an eminently fa-

* Professor of Astronomy, Cambridge University, England.

vorable position at Flagstaff, in Arizona. He has a superb telescope, and enjoys a perfect climate for astronomical work. Aided by skilful assistants, he has observed Mars under the most favorable circumstances with great care for some years. I must be permitted to say that, having carefully studied what Mr. Lowell has set forth, and having tested his facts and figures in every way in my power, most astronomers have come to the conclusion that, however astonishing his observations may seem to be, we cannot refuse to accept them.

No one has ever seen inhabitants on Mars, but Mr. Percival Lowell and one or two other equally favored observers have seen features on that planet which, so far as our experience goes, can be explained in no other way than by supposing that they were made by an intelligent designer for an intelligent purpose. Mr. Lowell has discovered that there are certain operations in progress on the surface of Mars which, if met with on this earth, we should certainly conclude, without the slightest hesitation, were the result of operations conducted under what we consider rational guidance.

A river, as Nature has made it, wends its way to and fro; it never takes the shortest route from one point to another; the width of the river is incessantly changing; sometimes it expands into a lake, sometimes it divides so as to inclose an island. If we could discern through our telescopes a winding line such as I have described on Mars it might perhaps represent a river.

But suppose, instead of a winding line, there was a perfectly straight line, or rather a great circle on the globe drawn as straight as a surveyor could lay it out—if we beheld an object like that on Mars I think we should certainly infer that it was not a river made in the ordinary course of natural operations; no natural river ever runs in that regular fashion. If such a straight line were indeed a river, then it must have been designedly straightened by human agency or by some other intelligent agency for some particular purpose. In its larger features Nature does not work by straight lines. A long and perfectly straight object, if found on our earth, might be a canal or it might be a road; it might be a railway or a terrace

of some kind; but assuredly no one would expect it to be a natural object.

We have the testimony of Schiaparelli, now strengthened by that of Mr. Lowell and his assistants, that there are many straight lines of this kind on Mars. They appear to be just as straight as a railway would have to be if laid across the flat and boundless prairie, where the engineer encountered no obstacle whatever to make him swerve from the direct path. These lines on Mars run for hundreds of miles, sometimes, indeed, I should say for thousands of miles. They are far wider than any terrestrial river, except perhaps the Amazon for a short part of its course. The lines on Mars are about forty miles wide. Indeed, the planet is so distant that if these lines were much narrower than forty miles they would be invisble. Each of them is marvelous in its uniformity throughout its entire length.

The existence of these straight lines on the planet contains perhaps the first suggestion of the presence of some intelligent beings on Mars. The mere occurrence of a number of perfectly straight, uniform lines on such a globe would in itself be a sufficiently remarkable circumstance. But there are other features exhibited by these objects which also suggest the astonishing surmise that they have been constructed by some intelligent beings for some intelligent purposes.

Sometimes two of these lines will start from a certain junction, sometimes there will be a third or a fourth from the same junction; in one case there are as many as seven radiating from the same point. Such an arrangement of these straight lines is certainly unlike anything that we find in Nature. We are led to seek for some other explanation of the phenomenon, and here is the explanation which Mr. Lowell offers:

It has recently been found that there are no oceans of water on the planet Mars. In earlier days it used no doubt to be believed that the dark marks easily seen in the telescope could represent nothing but oceans, but I think we must now give up the notion that these are watery expanses. Indeed, there is not much water on that globe anywhere in comparison with the abundance of water on our earth. It is the scarcity of

water which seems to give a clew to some of the mysteries discovered on Mars by Schiaparelli and Lowell.

As our earth moves round the sun we have, of course, the changing seasons of the year. In a somewhat similar manner Mars revolves around the sun, and accordingly this planet has also its due succession of seasons. There is a summer on Mars, and there is a winter; during the winter on that globe the poles of the planet are much colder than at other seasons, and the water there accumulates in the form of ice or snow to make those ice-caps that telescopic observers have so long noticed. In this respect Mars, of course, is like our earth. The ice-cap at each pole of our globe is so vast that even the hottest summer does not suffice to melt the accumulation; much of the ice and snow there remains to form the eternal snow which every arctic explorer so well knows. It would seem, however, that the contrast between winter and summer on Mars must be much more deeply marked than the contrast between winter and summer on our earth. During the summer of Mars ice and snow vanish altogether from the poles of that planet.

Mr. Lowell supposes that water is so scarce on Mars that the inhabitants have found it necessary to economize to the utmost whatever stock there may be of this most necessary element. The observations at Flagstaff tend to show that the dark lines on Mars mark the course of the canals by which the water melted in summer in the arctic regions is conducted over the globe to the tracts where the water is wanted. Not that the line as we see it represents actually the water itself; the straight line so characteristic of Mars's globe seems rather to correspond to the zones of vegetation which are brought into culture by means of water that flows along a canal in its center. In much the same way would the course of the Nile be exhibited to an inhabitant on Mars who was directing a telescope toward this earth: the river itself would not be visible, but the cultivated tracts which owe their fertility to the irrigation from the river would be broad enough to be distinguishable. The appearance of these irrigated zones would vary, of course, with the seasons; and we observe, as might have been expected,

changes in the lines on Mars corresponding to the changes in the seasons of the planet.

A noteworthy development of astronomy in the last century has been the erection of mighty telescopes for the study of the heavens. It must here suffice to mention, as the latest and most remarkable of these, the famous instrument at the Yerkes Observatory, which belongs to the University of Chicago. Just as the century is drawing to its close, the Yerkes telescope has begun to enter on its sublime task of exhibiting the heavens under greater advantages than have ever been previously afforded to any astronomers since the world began.

When the University of Chicago was founded, it was desired to associate with the university an astronomical observatory which should be worthy of the astonishing place that this wonderful city has assumed in the world's history. Mr. Yerkes, an American millionaire, generously undertook to provide the cost of this observatory. Two noble disks of glass, forty inches in diameter, were produced at the furnaces of Messrs. Mantois, in Paris; these disks were worked by Mr. Alvan Clark, of Boston, into the famous object glass which, weighing nearly half a ton, has now been mounted in what we may describe as a temple or a palace such as had never been dreamed of before in the whole annals of astronomy.

ASTRONOMY

The Starry Heavens

By SIR ROBERT BALL

WE are about to discuss one of the grandest truths in the whole of nature. We have had occasion to see that this sun of ours is a magnificent globe immensely larger than the greatest of his planets, while the greatest of these planets is immensely larger than this earth; but now we are to learn that our sun is, indeed, only a star not nearly so bright as many of those which shine over our heads every night. We are comparatively close to the sun, so that we are able to enjoy his beautiful light and cheering heat. Each of those other myriads of stars is a sun, and the splendor of those distant suns is often far greater than that of our own. We are, however, so enormously far from them that they appear dwindled down to insignificance. To judge impartially between our sun or star and such a sun or star as Sirius we should stand half way between the two; it is impossible to make a fair estimate when we find ourselves situated close to one star and a million times as far from the other. After allowance is made for the imperfections of our point of view, we are enabled to realize the majestic truth that the sun is no more than a star, and that the other stars are no less than suns. This gives us an imposing idea of the extent and magnificence of the universe in which we are situated. Look up at the sky at night—you will see a host of stars; try to think that every one of them is itself a sun. It may probably be that those suns have planets circling round them, but it is hopeless for us to expect to see such planets. Were you standing on one of those stars and looking

toward our system, you would not perceive the sun to be the brilliant and gorgeous object that we know so well. If you could see him at all, he would merely seem like a star, not nearly as bright as many of those you can see at night. Even if you had the biggest of telescopes to aid your vision, you could never discern from one of these bodies the planets which surround the sun; no astronomer in the stars could see Jupiter, even if his sight were a thousand times as powerful as any sight or telescope that we know. So minute an object as our earth would, of course, be still more hopelessly beyond the possibility of vision.

The Number of the Stars

To count the stars involves a task which lies beyond the power of man to accomplish. Even without the aid of any telescope, we can see a great multitude of stars from this part of the world. There are also many constellations in the southern hemisphere which never appear above our horizon. If, however, we were to go to the equator, then, by waiting there for a twelvemonth, all the stars in the heavens would have been successively exposed to view. An astronomer, Houzeau, with the patience to count them, enumerated about six thousand. This is the naked-eye estimate of the star-population of the heavens; but if instead of relying on unaided vision, you get the assistance of a little telescope, you will be astounded at the enormous multitude of stars which are disclosed.

An ordinary opera-glass or binocular is a very useful instrument for looking at the stars in the heavens. If you employ an instrument of this sort, you will be amazed to find that the heavens teem with additional hosts of stars that your unaided vision would never have given you knowledge of. Any part of the sky may be observed; but, just to give an illustration, take one special region, namely, that of the Great Bear. Of these seven well-known stars, four form a sort of oblong, while the other three represent the tail. I would like you to make this little experiment. On a fine clear night, count how many stars there are within this oblong; they are all very faint, but you

will be able to see a few, and, with good sight, and on a clear night, you may see perhaps ten. Next take your opera-glass and sweep it over the same region; if you will carefully count the stars it shows, you will find fully two hundred; so that the opera-glass has, in this part of the sky, revealed nearly twenty times as many stars as could be seen without its aid. As 6,000 stars can be seen by the eye all over the heavens, we may fairly expect that twenty times that number—that is to say, 120,000 stars—could be shown by the opera-glass over the entire sky. Let us go a step further, and employ a telescope, the object-glass of which is three inches across. This is a useful telescope to have, and, if a good one, will show multitudes of pleasing objects, though an astronomer would not consider it very powerful. An instrument like this, small enough to be carried in the hand, has been applied to the task of enumerating the stars in the northern half of the sky, and 320,000 stars were counted. Indeed, the actual number that might have been seen with it is considerably greater, for when the astronomer Argelander made this memorable investigation he was unable to reckon many of the stars in localities where they lay very close together. This grand count only extended to half the sky, and, assuming that the other half is as richly inlaid with stars, we see that a little telescope like that we have supposed will, when swept over the heavens, reveal more than one hundred times as many stars as our eyes could possibly reveal. Still, we are only at the beginning of the count; the very great telescopes add largely to the number. There are multitudes of stars which in small instruments we cannot see, but which are distinctly visible from our great observatories. That telescope would be still but a comparatively small one which would show 6,000,000; and with the greatest instruments, the tale of stars has risen to over 50,000,000.

In addition to those stars which the largest telescopes show us, there are myriads which make their presence evident in a wholly different way. It is only in quite recent times that an attempt has been made to develop fully the powers of photography in representing the celestial objects. On a photographic plate which has been exposed to the sky in a great telescope

the stars are recorded by thousands. Many of these may, of course, be observed with a good telescope, but there are not a few others which no one ever saw in a telescope, which apparently no one ever could see, though the photograph is able to show them. We do not, however, employ a camera like that which the photographer uses who is going to take your portrait. The astronomer's plate is put into his telescope, and then the telescope is turned towards the sky. On that plate the stars produce their images, each by its own light. Some of these images are excessively faint, but we give a very long exposure of an hour or two hours; sometimes as much as four hours' exposure is given to a plate so sensitive that a mere fraction of a second would sufficiently expose it during the ordinary practice of taking a photograph in daylight.

We thus afford sufficient time to enable the fainter objects to indicate their presence upon the sensitive film. Even with an exposure of a single hour a picture exhibiting 16,000 stars has been taken. Yet the portion of the sky which it represents is only one ten-thousandth part of the entire heavens.

Here, at last, we have obtained some conception of the sublime scale on which the stellar universe is constructed. Yet even these plates cannot represent all the stars that the heavens contain. We have every reason for knowing that with larger telescopes, with more sensitive plates, with more prolonged exposures, ever fresh myriads of stars will be brought into our view.

You must remember that every one of these stars is truly a sun, a lamp, as it were, which doubtless gives light to other objects in its neighborhood as our sun sheds light upon this earth and the other planets. In fact, to realize the glories of the heavens you should try to think that the brilliant points you see are merely the luminous points of the otherwise invisible universe.

Standing one fine night on the deck of a Cunarder we passed in open ocean another great Atlantic steamer. The vessel was near enough for us to see not only the light from the mast-head but also the little beams from the several cabin ports; and we could see nothing of the ship herself. Her very existence was

only known to us by the twinkle of these lights. Doubtless her passengers could see, and did see, the similar lights from our own vessel, and they probably drew the correct inference that these lights indicated a great ship.

Consider the multiplicity of beings and objects in a ship: the captain and the crew, the passengers, the cabins, the engines, the boats, the rigging, and the stores. Think of all the varied interests there collected, and then reflect that out on the ocean, at night, the sole indication of the existence of this elaborate structure was given by the few beams of light that happened to radiate from it. Now raise your eyes to the stars; there are the twinkling lights. We cannot see what those lights illuminate, we can only conjecture what untold wealth of non-luminous bodies may also lie in their vicinity; we may, however, feel certain that just as the few gleaming lights from a ship are utterly inadequate to give a notion of the nature and the contents of an Atlantic steamer, so are the twinkling stars utterly inadequate to give even the faintest conception of the extent and the interest of the universe. We merely see self-luminous bodies, but of the multitudes of objects and the elaborate systems of which these bodies are only the conspicuous points we see nothing and we know very little. We are, however, entitled to infer from an examination of our own star—the sun—and of the beautiful system by which it is surrounded, that these other suns may be also splendidly attended. This is quite as reasonable a supposition as that a set of lights seen at night on the Atlantic Ocean indicates the existence of a fine ship.

The Clusters of Stars

On a clear night you can often see, stretching across the sky, a track of faint light, which is known to astronomers as the "Milky Way." It extends below the horizon, and then round the earth to form a girdle about the heavens. When we examine the Milky Way with a telescope we find, to our amazement, that it consists of myriads of stars, so small and so faint that we are not able to distinguish them individually; we merely see the glow produced from their collective rays. Remember-

ing that our sun is a star, and that the Milky Way surrounds us, it would almost seem as if our sun were but one of the host of stars which form this cluster.

There are also other clusters of stars, some of which are exquisitely beautiful telescopic spectacles. I may mention a celebrated pair of these objects which lies in the constellation of Perseus. The sight of them in a great telescope is so imposing that no one who is fit to look through a telescope could resist a shout of wonder and admiration when first they burst on his view. But there are other clusters, such as that which is known as the "Globular Cluster in the Centaur." It consists of a ball of stars, so far off that, however large these several suns may actually be, they have dwindled down to extremely small points of light. A homely illustration may serve to show the appearance which a globular cluster presents in a good telescope. Take a pepper-caster, and on a sheet of white paper, shake out the pepper until there is a little heap at the center and other grains are scattered loosely about. Imagine that every one of those grains of pepper was to be transformed into a tiny electric light, and then you have some idea of what a cluster of stars would look like when viewed through a telescope of sufficient power. There are multitudes of such groups scattered through the depths of space. They require our biggest telescopes to show them adequately. We have seen that our sun is a star, being only one of a magnificent cluster that forms the Milky Way. We have also seen that there are other groups scattered through the length and depth of space. It is thus we obtain a notion of the rank which our earth holds in the scheme of things celestial.

The Distances of the Stars

Now about the distances of the stars. I shall not make the attempt to explain fully how astronomers make such measurements, but I will give you some notion of how it is done. We make the two observations from two opposite points on the earth's orbit, which are therefore at a distance of 186,000,000 miles. Imagine that on Midsummer Day, when standing on the

earth here, I measured with a piece of card the angle between the star and the sun. Six months later on, on Midwinter Day, when the earth is at the opposite point of its orbit, I again measure the angle between the same star and the sun, and we can now determine the star's distance by making a triangle. I draw a line a foot long, and we will take this foot to represent 186,000,000 miles, the distance between the two stations; then placing the cards at the corners, I rule the two sides and complete the triangle, and the star must be at the remaining corner; then I measure the sides of the triangle, and how many feet they contain, and recollecting that each foot corresponds to 186,000,000 miles, we discover the distance of the star. If the stars were comparatively near us, the process would be a very simple one; but, unfortunately, the stars are so extremely far off that this triangle, even with a base of only one foot, must have its sides many miles long. Indeed, astronomers will tell you that there is no more delicate or troublesome work in the whole of their science than that of discovering the distance of a star.

In all such measurements we take the distance from the earth to the sun as a conveniently long measuring-rod, whereby to express the results. The nearest stars are still hundreds of thousands of times as far off as the sun. Let us ponder for a little on the vastness of these distances. We shall first express them in miles. Taking the sun's distance to be 93,000,000 miles, then the distance of the nearest fixed star is about twenty millions of millions of miles—that is to say, we express this by putting down a 2 first, and then writing thirteen ciphers after it. It is, no doubt, easy to speak of such figures, but it is a very different matter when we endeavor to imagine the awful magnitude which such a number indicates. I must try to give some illustrations which will enable you to form a notion of it. At first I was going to ask you to try and count this number, but when I found it would require at least 300,000 years, counting day and night without stopping, before the task was over, it became necessary to adopt some other method.

When on a visit in Lancashire I was once kindly permitted to visit a cotton mill, and I learned that the cotton yarn there

produced in a single day would be long enough to wind round this earth twenty-seven times at the equator. It appears that the total production of cotton yarn each day in all the mills together would be on the average about 155,000,000 miles. In fact, if they would only spin about one-fifth more, we could assert that Great Britain produced enough cotton yarn every day to stretch from the earth to the sun and back again! It is not hard to find from these figures how long it would take for all the mills in Lancashire to produce a piece of yarn long enough to reach from our earth to the nearest of the stars. If the spinners worked as hard as ever they could for a year, and if all the pieces were then tied together, they would extend to only a small fraction of the distance; nor if they worked for ten years, or for twenty years, would the task be fully accomplished. Indeed, upwards of four hundred years would be necessary before enough cotton could be grown in America and spun in this country to stretch over a distance so enormous. All the spinning that has ever yet been done in the world has not formed a long enough thread!

There is another way in which we can form some notion of the immensity of these sidereal distances. You will recollect that, when we were speaking of Jupiter's moons, I told you of the beautiful discovery which their eclipses enabled astronomers to make. It was thus found that light travels at the enormous speed of about 185,000 miles per second. It moves so quickly that within a single second a ray would flash two hundred times from London to Edinburgh and back again.

We said that a meteor travels one hundred times as swiftly as a rifle-bullet; but even this great speed seems almost nothing when compared with the speed of light, which is 10,000 times as great. Suppose some brilliant outbreak of light were to take place in a distant star—an outbreak which would be of such intensity that the flash from it would extend far and wide throughout the universe. The light would start forth on its voyage with terrific speed. Any neighboring star which was at a distance of less than 185,000 miles would, of course, see the flash within a second after it had been produced. More distant bodies would receive the intimation after intervals of

time proportioned to their distances. Thus, if a body were 1,000,000 miles away, the light would reach it in from five to six seconds, while over a distance as great as that which separates the earth from the sun the news would be carried in about eight minutes. We can calculate how long a time must elapse ere the light shall travel over a distance so great as that between the star and our earth. You will find that from the nearest of the stars the time required for the journey will be over three years. Ponder on all that this involves. That outbreak in the star might be great enough to be visible here, but we could never become aware of it till three years after it had happened. When we are looking at such a star to-night we do not see it as it is at present, for the light that is at this moment entering our eyes has traveled so far that it has been three years on the way. Therefore, when we look at the star now we see it as it was three years previously. In fact, if the star were to go out altogether, we might still continue to see it twinkling for a period of three years longer, because a certain amount of light was on its way to us at the moment of extinction, and so long as that light keeps arriving here, so long shall we see the star showing as brightly as ever. When, therefore, you look at the thousands of stars in the sky to-night, there is not one that you see as it is now, but as it was years ago.

I have been speaking of the stars that are nearest to us, but there are others much farther off. It is true we cannot find the distances of these more remote objects with any degree of accuracy, but we can convince ourselves how great that distance is by the following reasoning. Look at one of the brightest stars. Try to conceive that the object was carried away farther into the depths of space, until it was ten times as far from us as it is at present, it would still remain bright enough to be recognized in quite a small telescope; even if it were taken to one hundred times its original distance it would not have withdrawn from the view of a good telescope; while if it retreated one thousand times as far as it was at first it would still be a recognizable point in our mightiest instruments. Among the stars which we can see with our telescopes, we feel confident there must be many from which the light has expended hun-

dreds of years, or even thousands of years, on the journey. When, therefore, we look at such objects, we see them, not as they are now, but as they were ages ago; in fact, a star might have ceased to exist for thousands of years, and still be seen by us every night as a twinkling point in our great telescopes.

Remembering these facts, you will, I think, look at the heavens with a new interest. There is a bright star, Vega, or Alpha Lyræ, a beautiful gem, so far off that the light from it which now reaches our eyes started before many of my audience were born. Suppose that there are astronomers residing on worlds amid the stars, and that they have sufficiently powerful telescopes to view this globe, what do you think they would observe? They will not see our earth as it is at present; they will see it as it was years (and sometimes many years) ago. There are stars from which if England could now be seen, the whole of the country would be observed at this present moment to be in a great state of excitement at a very auspicious event. Distant astronomers might notice a great procession in London, and they could watch the coronation of the youthful queen, Queen Victoria, amid the enthusiasm of a nation. There are other stars still further, from which, if the inhabitants had good enough telescopes, they would now see a mighty battle in progress not far from Brussels. One splendid army could be beheld hurling itself time after time against the immovable ranks of the other. There can be no doubt that there are stars so far away that the rays of light which started from the earth on the day of the battle of Waterloo are only just arriving there. Farther off still, there are stars from which a bird's-eye view could be taken at this very moment of the signing of Magna Charta. There are even stars from which England, if it could be seen at all, would now appear, not as the great England we know, but as a country covered by dense forests, and inhabited by painted savages, who waged incessant war with wild beasts that roamed through the island. The geological problems that now puzzle us would be quickly solved could we only go far enough into space and had we only powerful enough telescopes. We should then be able to view our earth through the successive epochs of past geological time; we should be actu-

ally able to see those great animals whose fossil remains are treasured in our museums, tramping about over the earth's surface, splashing across its swamps, or swimming with broad flippers through its oceans. Indeed, if we could view our own earth reflected from mirrors in the stars, we might still see Moses crossing the Red Sea, or Adam and Eve being expelled from Eden.

Double Stars

Whenever you have a chance of looking at the heavens through a telescope, you should ask to be shown what is called *a double star.* There are many stars in the heavens which present no remarkable appearance to the unaided eye, but which a good telescope at once shows to be of quite a complex nature. These are what we call double stars, in which two quite distinct stars are placed so close together that the unaided eye is unable to separate them. Under the magnifying power of the telescope, however, they are seen to be distinct. In order to give some notion of what these objects are like, I shall briefly describe three of them. The first lies in that best known constellation, the Great Bear. If you look at his tail, which consists of three stars, you will see that near the middle one of the three a small star is situated; we call this little star Alcor, but it is the brighter one near Alcor to which I specially call your attention. The sharpest eye would never suspect that it was composed of two stars placed close together. Even a small telescope will, however, show this to be the case, and this is the easiest and the first observation that a young astronomer should make when beginning to turn a telescope to the heavens. Of course you will not imagine that I mean Alcor to be the second component of the double star; it is the bright star near Alcor which is the double. Here are two marbles, and these marbles are fastened an inch apart. You can see them, of course, to be separate; but if the pair were moved further and further away, then you would soon not be able to distinguish between them, though the actual distance between the marbles had not altered. Look at these two wax tapers which are now lighted; the little flames are an inch apart. You would have

to view them from a station a third of a mile away if the distance between the two flames were to appear the same as that between the two components of this double star. Your eye would never be able to discriminate between two lights only an inch apart at so great a distance; a telescope would, however, enable you to do so, and this is the reason why we have to use telescopes to show us double stars.

You might look at that double star year after year throughout the course of a long life without finding any appreciable change in the relative positions of its components. But we know that there is no such thing as rest in the universe; even if you could balance a body so as to leave it for a moment at rest, it would not stay there, for the simple reason that all the bodies round it in every direction are pulling at it, and it is certain that the pull in one direction will preponderate, so that move it must. Especially is this true in the case of two suns like those forming a double star. Placed comparatively near each other they could not remain permanently in that position; they must gradually draw together and come into collision with an awful crash. There is only one way by which such a disaster could be averted. That is by making one of these stars revolve around the other just as the earth revolves around the sun, or the moon revolves around the earth. Some motion must, therefore, be going on in every genuine double star, whether we have been able to see that motion or not.

Let us now look at another double star of a different kind. This time it is in the constellation of Gemini. The heavenly twins are called Castor and Pollux. Of these, Castor is a very beautiful double star, consisting of two bright points, a great deal closer together than were those in the Great Bear; consequently a better telescope is required for the purpose of showing them separately. Castor has been watched for many years, and it can be seen that one of these stars is slowly revolving around the other; but it takes a very long time, amounting to hundreds of years, for a complete circuit to be accomplished. This seems very astonishing, but when you remember how exceedingly far Castor is, you will perceive that that pair of stars which appear so close together that it requires

a telescope to show them apart must indeed be separated by hundreds of millions of miles. Let us try to conceive our own system transformed into a double star. If we took our outermost planet—Neptune—and enlarged him a good deal, and then heated him sufficiently to make him glow like a sun, he would still continue to revolve round our sun at the same distance, and thus a double star would be produced. An inhabitant of Castor who turned his telescope towards us would be able to see the sun as a star. He would not, of course, be able to see the earth, but he might see Neptune like another small star close to the sun. If generations of astronomers in Castor continued their observations of our system, they would find a binary star, of which one component took a century and a half to go round the other. Need we then be surprised that when we look at Castor we observe movements that seem very slow?

There is often so much diffused light about the bright stars seen in a telescope, and so much twinkling in some states of the atmosphere, that stars appear to dance about in rather a puzzling fashion, especially to one who is not accustomed to astronomical observations. I remember hearing how a gentleman once came to visit an observatory. The astronomer showed him Castor through a powerful telescope as a fine specimen of a double star, and then, by way of improving his little lesson, the astronomer mentioned that one of these stars was revolving around the other. "Oh, yes," said the visitor, "I saw them going round and round in the telescope." He would, however, have had to wait for a few centuries with his eye to the instrument before he would have been entitled to make this assertion.

Double stars also frequently delight us by giving beautifully contrasted colors. I dare say you have often noticed the red and the green lights that are used on railways in the signal lamps. Imagine one of those red and one of those green lights away far up in the sky and placed close together, then you would have some idea of the appearance that a colored double star presents, though perhaps I should add that the hues in the heavenly bodies are not so vividly different as are those which our railway people find necessary. There is a particularly

beautiful double star of this kind in the constellation of the Swan. You could make an imitation of it by boring two holes, with a red-hot needle, in a piece of card, and then covering one of these holes with a small bit of the topaz-colored gelatine with which Christmas crackers are made. The other star is to be similarly colored with blue gelatine. A slide made on this principle placed in the lantern gives a very good representation of these two stars on the screen. There are many other colored doubles besides this one; and, indeed, it is noteworthy that we hardly ever find a blue or a green star by itself in the sky; it is always as a member of one of these pairs.

What the Stars are Made of

Here is a piece of stone. If I wanted to know what it was composed of, I should ask a chemist to tell me. He would take it into his laboratory, and first crush it into powder, and then, with his test tubes, and with the liquids which his bottles contain, and his weighing scales, and other apparatus, he would tell all about it; there is so much of this, and so much of that, and plenty of this, and none at all of that. But now, suppose you ask this chemist to tell you what the sun is made of, or one of the stars. Of course, you have not a sample of it to give him; how, then, can he possibly find out anything about it? Well, he can tell you something, and this is the wonderful discovery that I want to explain to you. We now put down the gas and I kindle a brilliant red light. Perhaps some of those whom I see before me have occasionally ventured on the somewhat dangerous practice of making fireworks. If there is any boy here who has ever constructed sky-rockets, and put the little balls into the top which are to burn with such vivid colors when the explosion takes place, he will know that the substance which tinged that fire red must have been strontium. He will recognize it by the color; because strontium gives a red light which nothing else will give. Here are some of these lightning papers, as they are called; they are very pretty and very harmless; and these, too, give brilliant red flashes as I throw them. The red tint, has, no doubt, been produced by

strontium also. You see we recognized the substance simply by the color of the light it produced when burning.

There are, in nature, a number of simple bodies called elements. Every one of these, when ignited under suitable conditions, emits a light which belongs to it alone, and by which it can be distinguished from every other substance. Many of the materials will yield light which will require to be studied by much more elaborate artifices than those which have sufficed for us. But you will see that the method affords a means of finding out the actual substances present in the sun or in the stars. There is a practical difficulty in the fact that each of the heavenly bodies contains a number of different elements; so that in the light it sends us the hues arising from distinct substances are blended into one beam. The first thing to be done is to get some way of splitting up a beam of light, so as to discover the components of which it is made. You might have a skein of silks of different hues tangled together, and this would be like the sunbeam as we receive it in its unsorted condition. How shall we untangle the light from the sun or a star? I will show you by a simple experiment. Here is a beam from the electric light; beautifully white and bright, is it not? It looks so pure and simple, but yet that beam is composed of all sorts of colors mingled together, in such proportions as to form white light. I take a wedge-shaped piece of glass called a prism, and when I introduce it into the course of the beam, you see the transformation that has taken place. Instead of the white light you have now all the colors of the rainbow—red, orange, yellow, green, blue, indigo, violet. These colors are very beautiful, but they are transient, for the moment we take away the prism they all unite again to form white light. You see what the prism has done; it has bent all the light in passing through it; but it is more effective in bending the blue than the red, and consequently the blue is carried away much farther than the red. Such is the way in which we study the composition of a heavenly body. We take a beam of its light, we pass it through a prism, and immediately it is separated into its components; then we compare what we find with the lights given by the different elements, and thus we are enabled

to discover the substances which exist in the distant object whose light we have examined. I do not mean to say that the method is a simple one; all I am endeavoring to show is a general outline of the way in which we have discovered the materials present in the stars. The instrument that is employed for this purpose is called the spectroscope. And perhaps you may remember that name by these lines, which I have heard from an astronomical friend:—

> "Twinkle, twinkle, little star,
> Now we find out what you are,
> When unto the midnight sky
> We the spectroscope apply."

I am sure it will interest everybody to know that the elements which the stars contain are not altogether different from those of which the earth is made. It is true there may be substances in the stars of which we know nothing here; but it is certain that many of the most common elements on the earth are present in the most distant bodies. I shall only mention one, the metal iron. That useful substance has been found in some of the stars which lie at almost incalculable distances from the earth.

The Nebulæ

I must say a few words about some dim and mysterious objects to which we have not yet alluded. They are what are called nebulæ, or little clouds; and in one sense they are justly called little, for each of them occupies but a very small spot in the sky as compared with that which would be filled by an ordinary cloud in our air. The nebulæ are, however, objects of the most stupendous proportions. Were our earth and thousands of millions of bodies quite as big all put together, they would not be nearly so great as one of these nebulæ. Astronomers reckon up the various nebulæ by thousands, but I must add that most of them are apparently faint and uninteresting. A nebula is sometimes liable to be mistaken for a comet. The comet is, as I have already explained, at once distinguished by the fact that it is moving and changing its appearance from

hour to hour, while scores of years elapse without changes in the aspect or position of a nebula. The most powerful telescopes are employed in observing these faint objects. A curious object in the constellation of Lyra can be seen under different telescopic powers. This is a gigantic ring of luminous gas. To judge of the size of this ring let us suppose that a railway were laid across it, and the train you entered at one side was not to stop until it reached the other side, how long do you think this journey would require? Let the train start at a speed of a mile a minute; you would think, surely, that it must soon cross the ring. But the minutes pass, an hour has elapsed; so the distance must be sixty miles at all events. The hours creep on into days, the days advance into years, and still the train goes on. The years would lengthen out into centuries, and even when the train had been rushing on for a thousand years with an unabated speed of a mile a minute the journey would certainly not have been completed. Nor do I venture to say what ages must elapse ere the terminus at the other side of the ring nebula would be reached.

A cluster of stars viewed in a small telescope will often seem like a nebula, for the rays of the stars become blended. A powerful telescope will, however, dispel the illusion and reveal the separate stars. It was, therefore, thought that all the nebulæ might be merely clusters so exceedingly remote that our mightiest instruments failed to resolve them into stars. But this is now known not to be the case. Many of these objects are really masses of glowing gas; such are, for instance, the ring nebulæ, of which I have just spoken.

ASTRONOMY

Comets

By CAMILLE FLAMMARION

THESE tailed bodies, which suddenly come to light up the heavens, were for long regarded with terror, like so many warning signs of Divine wrath. Men have always thought themselves much more important than they really are in the universal order; they have had the vanity to pretend that the whole creation was made for them, whilst in reality the whole creation does not suspect their existence. The earth we inhabit is only one of the smallest worlds, and therefore it can scarcely be for it alone that all the wonders of the heavens, of which the immense majority remains hidden from it, were created. In this disposition of man to see in himself the center and the end of everything, it was easy indeed to consider the steps of Nature as unfolded in his favor; and if some unusual phenomenon presented itself, it was considered to be without doubt a warning from Heaven. If these illusions had had no other result than the amelioration of the more timorous of the community one would regret these ages of ignorance; but not only were these fancied warnings of no use, seeing that, once the danger passed, man returned to his former state; but they also kept up among people imaginary terrors, and revived the fatal resolutions caused by the fear of the end of the world.

When one fancies the world is about to end—and this has been believed for more than a thousand years—no solicitude is felt in the work of improving this world; and, by the indifference or disdain into which one falls, periods of famine and general misery are induced which at certain times have overtaken

our community. Why use the wealth of a world which is going to perish? Why work, be instructed, or rise in the progress of the sciences or art? Much better to forget the world, and absorb one's self in the barren contemplation of an unknown life. It is thus that ages of ignorance weigh on man, and thrust him further and further into darkness, while science makes known, by its influence on the whole community, its great value and the magnitude of its aim.

The history of a comet would be an instructive episode of the great history of the heavens. In it could be brought together the description of the progressive movement of human thought, as well as the astronomical theory of these extraordinary bodies. Let us take, for example, one of the most memorable and best-known comets, and give an outline of its successive passages near the earth. Like the planetary worlds, comets belong to the solar system, and are subject to the rule of the Star King. It is the universal law of gravitation which guides their path; solar attraction governs them, as it governs the movement of the planets and the small satellites. The chief point of difference between them and the planets is, that their orbits are very elongated; and, instead of being nearly circular, they take the elliptical form. In consequence of the nature of these orbits, the same comet may approach very near the sun, and afterward travel from it to immense distances. Thus, the period of the comet of 1680 has been estimated at 3,000 years. It approaches the sun, so as to be nearer to it than our moon is to us, whilst it recedes to a distance eight hundred and fifty-three times greater than the distance of the earth from the sun. On the seventeenth of December, 1680, it was at its perihelion—that is, at its greatest proximity to the sun; it is now continuing its path beyond the Neptunian orbit. Its velocity varies according to its distance from the solar body. At its perihelion it travels thousands of leagues per minute; at its aphelion it does not pass over more than a few yards. Its proximity to the sun in its passage near that body caused Newton to think that it received a heat 28,000 times greater than that we experience at the summer solstice; and that this heat being 2,000 times greater than that of red-hot iron, an

iron globe of the same dimensions would be 50,000 years entirely losing its heat. Newton added that in the end comets will approach so near the sun that they will not be able to escape the preponderance of its attraction, and that they will fall one after the other into this brilliant body, thus keeping up the heat which it perpetually pours out into space. Such is the deplorable end assigned to comets by the author of the "Principia," an end which makes De la Brétonne say to Rétif: "An immense comet, already larger than Jupiter, was again increased in its path by being blended with six other dying comets. Thus displaced from its ordinary route by these slight shocks, it did not pursue its true elliptical orbit; so that the unfortunate thing was precipitated into the devouring center of the sun." "It is said," added he, "that the poor comet, thus burned alive, sent forth dreadful cries!"

It will be interesting, then, in a double point of view, to follow a comet in its different passages in sight of the earth. Let us take the most important in astronomical history—the one whose orbit has been calculated by Edmund Halley, and which was named after him. It was in 1682 that this comet appeared in its greatest brilliancy, accompanied with a tail which did not measure less than thirty-two millions of miles. By the observation of the path which it described in the heavens, and the time it occupied in describing it, this astronomer calculated its orbit, and recognized that the comet was the same as that which was admired in 1531 and 1607, and which ought to have reappeared in 1759. Never did scientific prediction excite a more lively interest. The comet returned at the appointed time; and on the twelfth of March, 1759, reached its perihelion. Since the year 12 before the Christian era, it had presented itself twenty-four times to the earth. It was principally from the astronomical annals of China that it was possible to follow it up to this period.

Its first memorable appearance in the history of France is that of 837, in the reign of Louis le Débonnaire. An anonymous writer of chronicles of that time, named "The Astronomer," gave the following details of this appearance, relative to the influence of the comet on the imperial imagination:

"During the holy days of the solemnization of Easter, a phenomenon ever fatal, and of gloomy foreboding, appeared in the heavens. As soon as the Emperor, who paid attention to these phenomena, received the first announcement of it, he gave himself no rest until he had called a certain learned man and myself before him. As soon as I arrived, he anxiously asked me what I thought of such a sign; I asked time of him, in order to consider the aspects of the stars, and to discover the truth by their means, promising to acquaint him on the morrow; but the Emperor, persuaded that I wished to gain time, which was true, in order not to be obliged to announce anything fatal to him, said to me: 'Go on the terrace of the palace and return at once to tell me what you have seen, for I did not see this star last evening, and you did not point it out to me; but I know that it is a comet; tell me what you think it announces to me.' Then, scarcely allowing me time to say a word, he added: 'There is still another thing you keep back; it is that a change of reign and the death of a prince are announced by this sign.' And as I advanced the testimony of the prophet, who said: 'Fear not the signs of the heavens as the nations fear them,' the prince with his grand nature, and the wisdom which never forsook him, said, 'We must not only fear Him who has created both us and this star. But as this phenomenon may refer to us, let us acknowledge it as a warning from Heaven.'"

Louis le Débonnaire gave himself and his court to fasting and prayer, and built churches and monasteries. He died three years later, in 840, and historians have profited by this slight coincidence to prove that the appearance of the comet was a harbinger of death. The historian, Raoul Glader, added later: "These phenomena of the universe are never presented to man without surely announcing some wonderful and terrible event."

Halley's comet again appeared in April, 1066, at the moment when William the Conqueror invaded England. It was pretended that it had the greatest influence on the fate of the battle of Hastings, which delivered over the country to the Normans.

A contemporary poet, alluding probably to the English

diadem with which William was crowned, had proclaimed in one place, "that the comet had been more favorable to William than nature had been to Cæsar; the latter had no hair, but William had received some from the comet." A monk of Malmesbury apostrophized the comet in these terms: "Here thou art again, thou cause of the tears of many mothers! It is long since I have seen thee, but I see thee now, more terrible than ever; thou threatenest my country with complete ruin!"

In 1455, the same comet made a more memorable appearance still. The Turks and Christians were at war, the West and the East seemed armed from head to foot—on the point of annihilating each other. The crusade undertaken by Pope Calixtus III. against the invading Saracens was waged with redoubled ardor on the sudden appearance of the star with the flaming tail. Mahomet II. took Constantinople by storm, and raised the siege of Belgrade. But the Pope having put aside both the curse of the comet and the abominable designs of the Mussulmans, the Christians gained the battle, and vanquished their enemies in a bloody fight. The *Angelus* to the sound of bells dates from these ordinances of Calixtus III. referring to the comet.

This ancient comet witnessed many revolutions in human history, at each of its appearances, even in its later ones, in 1682, 1759, 1835; it was also presented to the earth under the most diverse aspects, passing through a great variety of forms, from the appearance of a curved saber, as in 1456, to that of a misty head, as in its last visit. Moreover, this is not an exception to the general rule, for these mysterious stars have had the gift of exercising a power on the imagination which plunged it in ecstasy or trouble. Swords of fire, bloody crosses, flaming daggers, spears, dragons, fish, and other appearances of the same kind, were given to them in the Middle Ages and the Renaissance.

Comets like those of 1577 appear, moreover, to justify by their strange form the titles with which they are generally greeted. The most serious writers were not free from this terror. Thus, in a chapter on celestial monsters, the celebrated surgeon, Ambroise Paré, described the comet of 1528 under

the most vivid and frightful colors: "This comet was so horrible and dreadful that it engendered such great terror to the people, that they died, some with fear, others with illness. It appeared to be of immense length, and of blood color; at its head was seen the figure of a curved arm, holding a large sword in the hand as if it wished to strike. At the point of the sword there were three stars, and on either side was seen a great number of hatchets, knives, and swords covered with blood, amongst which were numerous hideous human faces, with bristling beards and hair."

The imagination has good eyes when it exerts itself. The great and strange variety of cometary aspects is described with exactitude by Father Souciet in his Latin poem on comets. "Most of them," says he, "shine with fires interlaced like thick hair, and from this they have taken the name of comets. One draws after it the twisted folds of a long tail; another appears to have a white and bushy beard; this one throws a glimmer similar to that of a lamp burning during the night; that one, O Titan! represents thy resplendent face; and this other, O Phœbe! the form of thy nascent horns. There are some which bristle with twisted serpents. Shall I speak of those armies which have sometimes appeared in the air? of those clouds which follow as it were along a circle, or which resemble the head of Medusa? Have there not often been seen figures of men or savage animals?

"Often, in the gloom of night, lighted up by these sad fires, the horrible sound of arms is heard, the clashing of swords which meet in the clouds, the ether furiously resounding with fearful din which crush the people with terror. All comets have a melancholy light, but they have not all the same color. Some have a leaden color; others that of flame or brass. The fires of some have the redness of blood; others resemble the brightness of silver. Some again are azure; others have the dark and pale color of iron. These differences come from the diversity of the vapors which surround them, or from the different manner in which they receive the sun's rays. Do you not see in our fires, that various kinds of wood produce different colors? Pines and firs give a flame mixed with thick smoke,

and throw out little light. That which rises from sulphur and thick bitumen is bluish. Lighted straw gives out sparks of a reddish color. The large olive, laurel, ash of Parnassus, etc., trees which always retain their sap, throw a whitish light similar to that of a lamp. Thus, comets whose fires are formed of different materials each take and preserve a color which is peculiar to them."

Instead of being a cause of fear and terror, the variety and variability of the aspect of comets ought rather to indicate to us the harmlessness of their nature.

GEOLOGY

The Glacial Epoch and Primitive Man

By ALFRED RUSSEL WALLACE

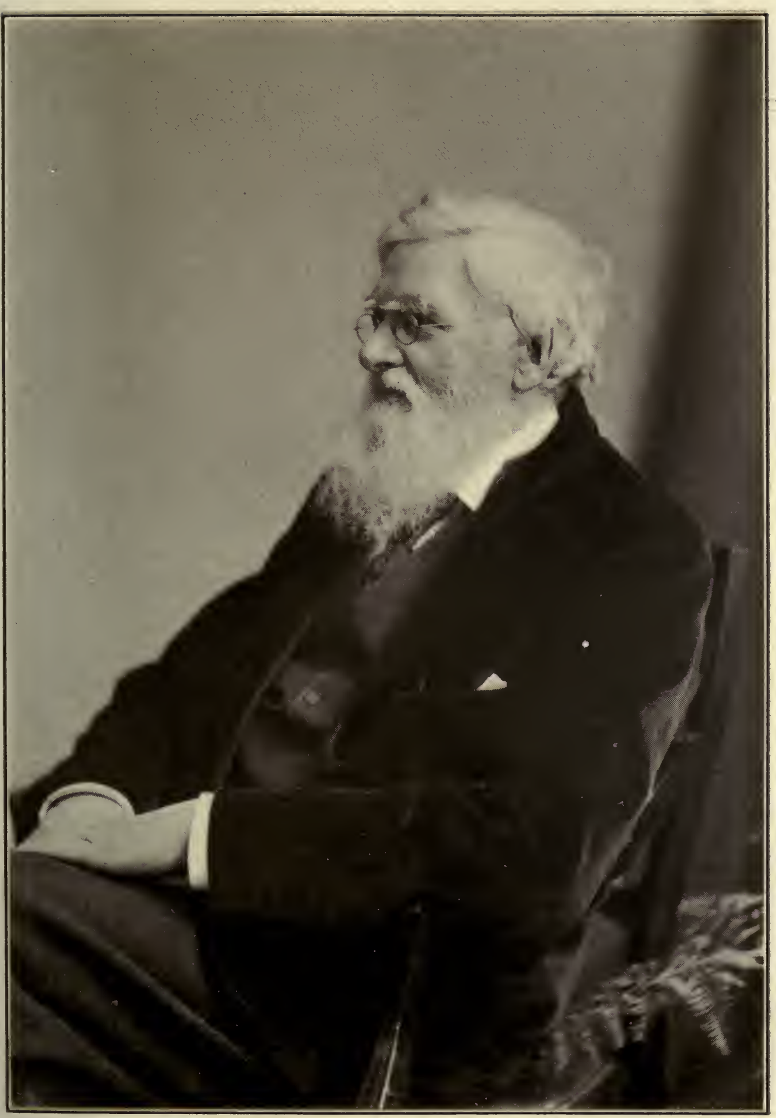
THE foundations of modern geology were laid, in the latter part of the last century, by Werner, Hutton, and William Smith, but most of the details and some of the more important principles have been wholly worked out during the present century. The great landmarks of its progress can alone be referred to here, namely (1) the establishment by Lyell of what has been termed the uniformitarian theory; (2) the proof of a recent glacial epoch and the working out of its effects upon the earth's surface; and (3) the discovery that man in the northern hemisphere lived contemporaneously with many now extinct animals.

In the early part of the century, and so late as the year 1830, Cuvier's "Essay on the Theory of the Earth" held the field as the exponent of geological theory. A fifth edition of the English translation appeared in 1827, and a German translation so late as 1830. In this work it was maintained that almost all geological phenomena pointed to a state of the earth and of natural forces very different from what now exists. In the raised beds of shells, in fractured rocks, in vertical stratification, we were said to have proofs "that the surface of the globe has been broken up by revolutions and catastrophes." The differences in the character of adjacent stratified deposits showed that there must have been various successive irruptions of the sea over the land; and Cuvier maintained that these irruptions and retreats of the sea were not slow or gradual, "but that most of the catastrophes which have occasioned them

have been sudden." He urged that the sharp and bristling ridges and peaks of the primitive mountains "are indications of the violent manner in which they have been elevated"; and he concludes that "it is in vain we search among the powers which now act at the surface of the earth for causes sufficient to produce the revolutions and catastrophes, the traces of which are exhibited in its crust." This theory of convulsions and catastrophes held almost universal sway within the memory of persons now living; for although Hutton and Playfair had advanced far more accurate views, they appear to have made little impression, while the great authority attached to Cuvier's name carried all before it.

But in 1830, while Cuvier was at the height of his fame, and his book was still being translated into foreign languages, a hitherto unknown writer published the first volume of a work which struck at the very roots of the catastrophe theory, and demonstrated, by a vast array of facts and the most cogent reasoning, that almost every portion of it was more or less imaginary and in opposition to the plainest teachings of nature. The victory was complete. From the date of the publication of the "Principles of Geology" there were no more English editions of "The Theory of the Earth."

Lyell's method was that of a constant appeal to the processes of nature. Before asserting that certain results could not be due to existing causes he carefully observed what those causes were now doing. He applied to them the tests of accurate measurement, and he showed that, taking into account the element of long-continued action, they were, in almost every case, fully adequate to explain the observed phenomena. He showed that modern volcanoes had poured out equally vast masses of melted rock, which had covered equally large areas, with any ancient volcano; that strata were now forming, comparable in extent and thickness with any ancient strata; that organic remains were being preserved in them, just as in the older formations; that land was almost everywhere either rising or sinking, as of old; that valleys were being excavated and mountains worn away; that earthquake shocks were producing faults in the rocks; that vegetation was now preparing future coal-beds;



ALFRED RUSSEL WALLACE.

that limestones, sandstones, metamorphic and igneous rocks were still being formed; and that, given time, and the intermittent or continuous action of the causes we can now trace in operation, all the contortions and fractures of strata, all the ravines and precipices, and every other modification of the earth's crust supposed to imply the agency of sudden revolutions and violent catastrophes may be again and again produced.

During a period of more than forty years Sir Charles Lyell continued to enlarge and improve his work, bringing out eleven editions, the last of which was published three years before his death; and rarely has any scientific work so completely justified its title, since it remains to this day the best exposition of the "Principles of Geology"—the foundation on which the science itself must be and has been built. The disciples and followers of Lyell have been termed "Uniformitarians," on account of their belief that the causes which produced the phenomena manifested to us in the crust of the earth are essentially of the same nature as those acting now. And, as is often the case, the use of the term as a nickname has led to a misconception as to the views of those to whom it is applied. A few words on this point are therefore called for.

Modern objectors say that it is unphilosophical to maintain that in our little experience of a few hundred, or at most a few thousand, years, we can have witnessed all forms and degrees of the action of natural forces; that we have no right to take the historical period as a fair sample of all past geological ages; and that, as a mere matter of probability, we ought to expect to find proofs of greater earthquakes, more violent eruptions, more sudden upheavals, and more destructive floods, having occurred during the vast eons of past time. Now this argument is perfectly sound if limited to the occurrence of extreme cases, but not if applied to averages. No Uniformitarian will deny the probability of there having been *some* greater convulsions in past geological ages than have ever been experienced during the historical period. But modern convulsionists do not confine themselves to this alone, but maintain that, *as a rule*, all the great natural forces tending to modify the surface of the earth were more powerful and acted on a larger scale than they

do now. On the ground of mere probability, however, we have no right to assume a diminution rather than an increase of natural forces in recent times, unless there is some proof that these forces have diminished. Sir Charles Lyell shows that the cases adduced as indicating greater forces in the past are fallacious, and his doctrine is simply one of real as against imaginary forces.

But our modern objectors have another argument, founded upon the admitted fact that the earth has cooled and is slowly cooling, and was probably once in a molten condition. They urge that in early geological times, when the earth was hotter, the igneous, aqueous, and aerial forces were necessarily greater, and would produce more rapid changes and greater convulsions than now. This is a purely theoretical conclusion, by no means sure, and perhaps the very reverse of what really occurred. There are two reasons for this belief, which may be very briefly stated. After the earth's crust was once formed it cooled very slowly, and the crust became very gradually thicker. So far as the action of the molten interior on the crust may have produced convulsions they should become not less, but more violent as the crust becomes thicker. With a thin crust any internal tension will be more frequently relieved by fracture or bending, and the resulting disturbances will be *less* violent; but as the crust becomes thicker, internal tensions will accumulate, and when relieved by fracture the disturbance will be *more* violent.

As regards storms and other aerial disturbances, these also would probably be less violent when the temperature of the whole surface was more uniform as well as warmer, and the atmosphere consequently so full of vapor as to prevent the sun's rays from producing the great inequalities of temperature that now prevail. It is these inequalities that produce the great aerial disturbances of our era, which arise from the heated surfaces of the bare plains and deserts of the subtropical and warm temperate belts. In the equatorial belt (10° each side of the equator), where the heat is more uniform and the surface generally well clothed with vegetation, tornadoes and hurricanes are almost unknown.

There remains only the action of the tides upon coasts and estuaries, which may have been greater in early geological times, if, as is supposed, the moon was then considerably nearer to the earth than it is now. But this is a comparatively unimportant matter as regards geological convulsions, because its maximum effects recur at short intervals and with great regularity, so that both vegetation and the higher forms of animal life would necessarily be limited to the areas which were beyond its influence.

It thus appears that, so far from there being any theoretical necessity for greater violence of natural forces in early geological times, there are some weighty reasons why the opposite should have been the case; while all the evidence furnished by the rocks themselves, and by the contours of the earth's surface, are in favor of a general uniformity, with, of course, considerable local variability.

It is interesting to note the very different explanations of the commonest features of the earth's surface given by the old and by the new theories. In every mountain region of the globe deep valleys, narrow ravines, and lofty precipices are of common occurrence, and these were, by the old school, almost always explained as being due to convulsions of nature. In ravines, we were taught that the rocks had been "torn asunder," while the mountains and the precipices were indications of "sudden fractures and upheavals of the earth's crust." On the new theory, these phenomena are found to be almost wholly due to the slow action of the most familiar every-day causes, such as rain, snow, frost, and wind, with rivers, streams, and every form of running water, acting upon rocks of varying hardness, permeability, and solubility. Every shower of rain falling upon steep hillsides or gentle slopes, while partially absorbed, to a large extent runs over the surface, carrying solid matter from higher to lower levels. Every muddy stream or flooded river shows the effect of this action. Day and night, month after month, year after year, this denudation goes on, and its cumulative effects are enormous. The material is supplied from the solid rocks, fractured and decomposed by the agency of snow and frost or by mere variations of temperature,

and primarily by those interior earth movements which are continually cleaving, fissuring, and faulting the solid strata, and thus giving the superficial causes of denudation facilities for action. The amount and rate of this superficial erosion and denudation of the earth's surface can be determined by the quantity of solid matter carried down by the rivers to the sea. This has been measured with considerable accuracy for several important rivers; and by comparing the quantity of matter, both in suspension and solution, with the area of the river basin, we know exactly the average amount of lowering of the whole surface per annum. It has thus been calculated that

The Mississippi	removes	one foot	of the surface	of its basin in	6,000	years
" Ganges	"	"	"	"	2,358	"
" Hoang Ho	"	"	"	"	1,464	"
" Rhône	"	"	"	"	1,528	"
" Danube	"	"	"	"	6,846	"
" Po	"	"	"	"	729	"
" Nith	"	"	"	"	4,723	"

The average of these rivers gives us one foot as the lowering of the land by sub-aerial denudation in 3,000 years, or a thousand feet in three million years; but as Europe has a mean altitude of less than a thousand feet, it follows that, at the present rate of denudation, the whole of Europe would be reduced to nearly the sea-level in about three million years. Before this method of measuring the rate of the lowering of continents was hit upon by Mr. Alfred Tylor in 1853, no one imagined that it was anything like so rapid; and, as a million years is certainly a short period as compared with the whole geological record, it is clear that elevation must, on the whole, have always kept pace with the two lowering agencies—sinking and denudation. Again, as in every continent the areas occupied by plains and lowlands, where denudation is comparatively slow, are large as compared with the mountain areas, where all the denuding agencies are most powerful, it is probable that most mountain ranges are being lowered at perhaps ten times the

above average rate, and many mountain peaks and ridges perhaps a hundred times.

Examples of the rapidity of denudation as compared with earth-movements are to be found everywhere. In disturbed regions, faults of many hundreds, and sometimes even thousands of feet, are not uncommon; yet there is often no inequality on the surface, indicating that the dislocation of strata has been caused by small and often-repeated movements, at such intervals that denudation has been able to remove the elevated portion as it arose. Again, when the strata are bent into great folds or undulations, it is only rarely that the tops of the folds correspond to ridges and the depressions to valleys. Frequently the reverse is the case, a valley running along the anticlinal line or structural ridge, while the synclinal or structural hollow forms a mountain top; while, in other cases, valleys cut across these structural features, with little or no regard to them. This results from the fact that it is not mountains or mountain ranges, as we see them, which have been raised by internal forces, but a considerable area, already perhaps much disturbed and dislocated by earth-movements, has been slowly raised till it became a kind of table-land. From its first elevation above the sea, however, it would have been exposed to rainfall, and the water, flowing off in the direction of least resistance, would have formed a number of channels radiating from the highest portion, and thus establishing the first outlines of a system of valleys, which go on deepening as the land goes on rising, often quite irrespective of the nature of the rocks beneath. This explains the close resemblance in the general arrangement of valleys in all high regions, as well as the very common phenomenon of a river crossing the main range of a mountain system by a deep gorge; for this merely shows that what is now the highest part of the range was at first lower than that where the river has its source, but has become higher by the more rapid degradation of the lateral ranges, owing to their being formed of rock which is more easily disintegrated. The various peculiarities of open valley and narrow gorge, of sloping mountain-side or lofty precipice, of rivers cutting across hills, as in the South Downs and at Clifton, when open plains

by which they might apparently have reached the sea are near at hand, may be all explained as the results of those simple causes which are everywhere in action around us. It was Sir Charles Lyell who first convinced the whole scientific world of the efficacy of these familiar agents; and the secure establishment of this doctrine constitutes one of the great philosophical landmarks of the nineteenth century.

The Glacial Epoch

The proof of the recent occurrence in the north temperate zone of a glacial epoch, during which large portions of Europe and North America were buried in ice, may, from one point of view, be thought to prove that other agents than those now in operation have acted in past ages, and thus to disprove the main assumption of the Uniformitarians. But, on the other hand, its existence has been demonstrated by those very methods which Sir Charles Lyell advocated—the accurate observation of what nature is doing now; while an ice age really exists at the present time in Greenland, in the same latitude as nearly the whole of Sweden and Norway, which enjoy a comparatively mild climate.

The first clear statement of the evidence for a former ice age was given, in 1822, by a Swiss engineer named Venetz. He pointed out that, where the existing glaciers have retreated, the rocks which they had covered are often rounded, smoothed, and polished, or grooved and striated in the direction of the glacier's motion; and that, far away from any existing glaciers, there were to be seen rocks similarly rounded, polished, and striated; while there also existed old moraine heaps exactly similar to those formed at present; and that these phenomena extended as far as the Jura range, on the flanks of which there were numbers of huge blocks of stone, of a kind not found in those mountains, but exactly similar to the ancient rocks of the main Alpine chain. Hence, he concluded that glaciers formerly extended down the Rhône valley as far as the Jura, and there deposited those erratic blocks, the presence of which had puzzled all former observers.

Soon afterward, Charpentier and Agassiz devoted themselves to the study of the records left by the ancient glaciers; and from that time to the present a band of energetic workers in every part of the world have, by minute observation and reasoning, established the fact of the extension of glaciers, or ice-sheets, over a large portion of the north temperate zone; and have also determined the direction of their motion and the thickness of the ice in various parts of their course. These conclusions are now admitted by every geologist who has devoted himself to the subject, and are embodied in the various official geological surveys of the chief civilized countries; and as they constitute one of the most remarkable chapters in the past history of the globe, and especially as this great change of climate occurred during the period of man's existence on the earth, a brief sketch of the facts must be here given.

There are four main groups of phenomena which demonstrate the former existence of glaciers in areas where they are now absent: (1) Moraines, and glacial drifts or gravels; (2) Smoothed, rounded, or planed rocks; (3) Striæ, grooves, and furrows on rock-surfaces; (4) Erratics and perched blocks.

(1) Moraines are formed by all existing glaciers, consisting of the earth and rocks which fall upon the ice-rivers from the sides of the valleys through which they flow. The slow motion of the glacier carries these down with it, and they are deposited in great heaps where it melts. In some glaciers where the tributary valleys are numerous and the *débris* that falls upon the ice is abundant, the whole of the lower part of the glacier for many miles is so buried in it that the surface of the ice cannot be seen, and in these cases there will be a continuous moraine formed across the valley where the glacier terminates. The characteristics of moraines are, that they consist of varied materials, earth, gravel, and rocks of various sizes intermingled confusedly; and they often form mounds or ridges completely across a valley, except where the stream passes through it, while in other cases they extend laterally along the slopes of the hillsides, where, owing to the form of the valley, the glacier has shrunk laterally and left its lateral moraine behind it. In many cases huge blocks of rock rest on the very summit of a

moraine, or, in the case of lateral moraines, on the very edge of a precipice in positions where no known agency but ice could have deposited them. These are called "perched blocks." Drifts or glacial gravels are deposits of material similar to that forming the moraines, but spread widely over districts which have formerly been buried in ice. These are often partially formed of stiff clay, in which are embedded quantities of smoothed and striated stones; but the great characteristic of all these ice-products is that the materials are not stratified—that is, sorted according to their fineness or coarseness, as is always the case when deposited by water—but are mingled confusedly together, the large stones being scattered all through the mass, and usually being quite as abundant at the top as at the bottom of the deposit. Such deposits are to be found all over the north and northwest of our islands, and are often well exhibited in railway cuttings; and wherever they are well developed, and the materials of which they consist differ from those forming the underlying rocks, they are an almost infallible indication of the former existence of a glacier or ice-sheet.

(2) The smoothed and rounded rocks called in Switzerland *roches moutonnées*, from their resemblance at a distance to recumbent sheep, are present in almost all recently glaciated mountainous countries, especially where the rocks are very hard. They are to be seen in all the higher valleys of Wales, the Lake District, and Scotland, and on examination are found to consist often of the hardest and toughest rocks. In other cases the rock forming the bed of the valley is found to be planed off smooth, even when it consists of hard crystalline strata thrown up at a high angle, and which naturally weathers into a jagged or ridged surface.

(3) The smoothed rocks are often found to be covered with numerous striæ, deep grooves, or huge flutings, and these are almost always in one direction, which is that of the course of the glacier. They may often be traced in the same direction for miles, and do not change in harmony with the lesser inequalities of the valley, as they would certainly do had they been formed by water action. These striæ and smoothed rocks are often found hundreds or even thousands of feet above the floor

of the valley, and in many cases a definite line can be traced, above which the rocks are rugged and jagged, while below it they are more or less rounded, smooth, or polished.

(4) Erratic blocks are among the most widespread and remarkable indications of glacial action, and they were the first that attracted the attention of men of science. The great plains of Denmark, Prussia, North Germany, and Russia are strewn with large masses of granite and hard metamorphic rocks, and these rest either on glacial drift or on quite different rocks of Secondary or Tertiary age. In parts of North Germany they are so abundant as to hide the natural surface, and they are often piled up in irregular heaps forming hills of granite bowlders covered with forests of pine, birch, and juniper. Many of these blocks are more than a thousand tons' weight, and almost all of them can be traced to the mountains of Scandinavia as their source. Many of the largest blocks have been carried furthest from the parent rock—a fact which is conclusive against their having been brought to their present position by the action of floods.

The most interesting and instructive erratic blocks are those found upon the slopes of the Jura, because they have been most carefully studied by Swiss and French geologists, and have all been traced to their sources in the Alpine chain. The Jura mountains consist wholly of Secondary limestones, and are situated opposite to the Bernese Alps, at a distance of about fifty miles. Along their slopes for a distance of a hundred miles, and extending from their base to a height of 2,000 feet above the Lake of Neuchâtel, are great numbers of rocks, some of them as large as houses, and always quite different from that of which the Jura range is formed. These have all been traced to their parent rocks in various parts of the course of the old glacier of the Rhône, and, what is even more remarkable, their distribution is such as to prove that they were conveyed by a glacier and not by floating ice during a period of submergence. The rocks and other *débris* that fall upon a glacier from the two sides of its main valley form distinct moraines upon its surface, and however far the glacier may flow, and however much it may spread out where the valley

widens, they preserve their relative position so that whenever they are deposited by the melting of the glacier, those that came from the north side of the valley will remain completely separated from those which came from the south side. It was this fact which convinced Sir Charles Lyell that the theory of floating ice, which he had first adopted, would not explain the distribution of the erratics, and he has given in his "Antiquity of Man" (4th ed., p. 344) a map showing the course of the blocks as they were conveyed on the surface of the glacier to their several destinations. Other blocks are found on the lower slopes of the Alpine chain toward Bern on one side and Geneva on the other, while the French geologists have traced them down the Rhône valley seventy miles from Geneva, and also more than twenty miles west of the Jura, thus proving that at the lowest portion of that chain the glacier flowed completely over it. In all these cases the blocks can be traced to a source corresponding to their position on the theory of glacier action. Some of these rocks have been carried considerably more than two hundred miles, proving that the old glacier of the Rhône extended to this enormous distance from its source.

In our own islands and in North America these various classes of evidence have been carefully studied, the direction of the glacial striæ everywhere ascertained, and all the more remarkable erratic blocks traced to their sources, with the result that the extent and thickness of the various glaciers and ice-sheets are well determined and the direction of motion of the ice ascertained. The conclusions arrived at are very extraordinary, and must be briefly indicated.

In Great Britain, during the earlier and later phases of the ice age, all the mountains of Scotland, the Lake District, and Wales produced their own glaciers, which flowed down to the sea. But at the time of the culmination of the Glacial Epoch the Scandinavian ice-sheet extended on the southeast till it filled up the Baltic Sea and spread over the plains of northwestern Europe, and also filled up the North Sea, joining the glaciers of Scotland, forming with them a continuous ice-sheet from which the highest mountains alone protruded. At the same time this Scotch ice-sheet extended into the Irish Sea,

and united with the glaciers of the Lake District, Wales, and Ireland till almost continuous ice-sheets enveloped those countries also. Glacial striæ are found up to a height of 3,500 feet in Scotland and 2,500 feet in the Lake District and in Ireland; while the Isle of Man was completely overflowed, as shown by glacial striæ on the summit of its loftiest mountains. Erratics from Scandinavia are found in great quantities on Flamborough Head, mixed with others from the Lake District and Galloway, showing that two ice streams met here from opposite directions. Erratics from Scotland are also found in the Lake District, in North Wales, in the Isle of Man, and in Ireland, from which the direction of the moving ice can be determined. Great numbers of local rocks have also been carried into places far from their origin, and in every case this displacement is in the direction of the flow of the ice as ascertained by the other evidence—never in the opposite direction. Each great mountain area had, however, its own center of local dispersal, depending upon the position of greatest thickness of the ice-sheet, which was not necessarily that of the highest mountains, but was approximately the center of the main area of glaciation. Thus the center of the North Wales ice-sheet was not at Snowdon, but over the Arenig mountains, which thus became a local center of dispersal of erratics. In Ireland, the mountains being placed around the coasts, the great central plain became filled with ice which, continually accumulating, formed a huge dome of ice whose outward pressure caused motion in all directions till checked by the opposing motion of the great Scandinavian ice-sheet. This strange fact has been demonstrated by the work of the Irish Geological Survey and by many local geologists, and is universally accepted by all who have studied the evidence. The great outlines of the phenomena of the ice age in our islands are now as thoroughly well established as any of the admitted conclusions of geological science. In our own country the ice extended more or less completely over the whole of the midland counties and as far south as the Thames Valley.

When we cross the Atlantic the phenomena are equally remarkable. The whole of the northeastern United States and

Canada were also buried in an ice-sheet of enormous thickness and extent. It came southward as far as New York, and inland, in an irregular line, by Cincinnati, to St. Louis on the Mississippi. The whole of the region to the north of this line is covered with a deposit of drift, often of enormous thickness, while embedded in the drift, or scattered over its surface, are numbers of blocks and rock-masses, often formed of materials quite foreign to the bed-rock of the district. These erratics have in many cases been traced to their sources, sometimes six hundred miles away, and the study of these, and of the numerous grooved and striated rocks, show that the center of dispersal was far north of the Alleghanies and its outliers, and, as in the case of Ireland, must have consisted of a huge dome of ice situated over the plateau to the north of the Great Lakes, in what must have been an area of great snow-fall combined with a very low temperature. The maximum thickness of this great ice-sheet must have been at least a mile over a considerable portion of its area, as glacial deposits have been found on the summit of Mount Washington at an altitude of nearly 6,000 feet, and the center of motion was a considerable distance to the northwest, where it must have reached a still greater altitude.

The complete similarity of the conclusions reached by four different sets of observers in four different areas—Switzerland, northwestern Europe, the British Isles, and North America—after fifty years of continuous research, and after every other less startling theory had been put forth and rejected as wholly inconsistent with the phenomena to be explained, renders it as certain as any conclusion from indirect evidence can be, that a large portion of the north temperate zone, now enjoying a favorable climate and occupied by the most civilized nations of the world, was, at a very recent epoch, geologically speaking, completely buried in ice, just as Greenland is now. How recently the ice has passed away is shown by the perfect preservation of innumerable moraines, perched blocks, erratics, and glaciated rock-surfaces, showing that but little denudation has occurred to modify the surface; while undoubted relics of man found in glacial or interglacial deposits prove that it occurred

during the human period. It is clear that man could not have lived in any area while it was actually covered by the ice-sheet, while any indications of his presence at an earlier period would almost certainly be destroyed by the enormous abrading and grinding power of the ice.

Besides the areas above referred to, there are widespread indications of glaciation in parts of the world where a temperate climate now prevails. In the Pyrenees, Caucacus, Lebanon, and Himalayas glacial moraines are found far below the lower limits they now attain. In the Southern Hemisphere similar indications are found in New Zealand, Tasmania, and the southern portion of the Andes; but whether this cold period was coincident with that of the Northern Hemisphere we have at present no means of determining, nor even whether they were coincident among themselves, since it is quite conceivable that they may have been due to local causes, such as greater elevation of the land, and not to any general cause acting throughout the south temperate zone.

In the north temperate zone, however, the phenomena are so widespread and so similar in character, with only such modifications as are readily explained by proximity to, or remoteness from, the ocean, that we are almost sure they must have been simultaneous, and have been due to the same general causes, though perhaps modified by local changes in altitude and consequent modification of winds or ocean-currents. The time that has elapsed since the glaciation of the Northern Hemisphere passed away is, geologically, very small indeed, and has been variously estimated at from 20,000 to 100,000 years. At present the smaller period is most favored by geologists, but the duration of the ice age itself, including probably one or more inter-glacial mild periods, is admitted to be much longer, and probably to approach the higher figure above given.

The undoubted fact, however, that a large part of the north temperate zone has been recently subjected to so marvelous a change of climate, is of immense interest from many points of view. It teaches us in an impressive way how delicate is the balance of forces which renders what are now the most densely peopled areas habitable by man. We can hardly suppose that

even the tremendously severe ice age of which we have evidence is the utmost that can possibly occur; and, on the other hand, we may anticipate that the condition of things which in earlier geological times rendered even the polar regions adapted for a luxuriant woody vegetation may again recur, and thus vastly extend the area of our globe which is adapted to support human life in abundance and comfort. In the endeavor to account for the change of climate and of physical geography which brought about so vast a change, and then, after a period certainly approaching, and perhaps greatly exceeding, a hundred thousand years, caused it to pass away, some of the most acute and powerful intellects of our day have exerted their ingenuity; but, so far as obtaining general acceptance for the views of any one of them, altogether in vain. There seems reason to believe, however, that the problem is not an insoluble one; and when the true cause is reached, it will probably carry with it the long-sought datum from which to calculate with some rough degree of accuracy the duration of geological periods. But, whether we can solve the problem of its cause or no, the demonstration of the recent occurrence of a Glacial Epoch or Great Ice Age, with the determination of its main features over the Northern Hemisphere, will ever rank as one of the great scientific achievements of the nineteenth century.

The Antiquity of Man

Following the general acceptance of a glacial epoch by about twenty years, but to some extent connected with it, came the recognition that man had existed in Northern Europe along with numerous animals which no longer live there—the mammoth, the woolly rhinoceros, the wild horse, the cave-bear, the lion, the sabre-toothed tiger, and many others—and that he had left behind him, in an abundance of rude flint implements, the record of his presence. Before that time geologists, as well as the whole educated world, had accepted the dogma that man appeared upon the earth only when both its physical features and its animal and vegetable forms were exactly as we find them to-day; and this belief, resting solely on negative evi-

dence, was so strongly and irrationally maintained that the earlier discoveries could not get a hearing. A careful but enthusiatic French observer, M. Boucher de Perthes, had for many years collected with his own hands, from the great deposits of old river gravels in the valley of the Somme near Amiens, abundance of large and well-formed flint implements. In 1847 he published an account of them, but nobody believed his statements, till, ten years later, Dr. Falconer, and shortly afterward Professor Prestwich and Mr. John Evans, examined the collections and the places where they were found, and were at once convinced of their importance; and their testimony led to the general acceptance of the great antiquity of the human race. From that time researches on this subject have been carried on by many earnest students, and have opened up a number of altogether new chapters in human history.

So soon as the main facts were established, many old records of similar discoveries were called to mind, all of which had been ignored or explained away on account of the strong prepossession in favor of the very recent origin of man. In 1715 flint weapons had been found in excavations near Gray's Inn Lane, along with the skeleton of an elephant. In 1800 another discovery was made in Suffolk of flint weapons and the remains of extinct animals in the same deposits. In 1825 Mr. McEnery, of Torquay, discovered worked flints along with the bones and teeth of extinct animals in Kent's cavern. In 1840 a good geologist confirmed these discoveries, and sent an account of them to the Geological Society of London, but the paper was rejected as being too improbable for publication! All these discoveries were laughed at or explained away, as the glacial striæ and grooves so beautifully exhibited in the Vale of Llanberris were at first endeavored to be explained as the wheel-ruts caused by the chariots of the ancient Britons! These, combined with numerous other cases of the denial of facts on *a priori* grounds, have led me to the conclusion that, whenever the scientific men of any age disbelieve other men's careful observations without inquiry, the scientific men are *always* wrong.

Even after these evidences of man's great antiquity were

admitted, strenuous efforts were made to minimize the time as measured by years; and it was maintained that man, although undoubtedly old, was entirely post-glacial. But evidence has been steadily accumulating of his existence at the time of the glacial epoch, and even before it; while two discoveries of recent date seem to carry back his age far into pre-glacial times. These are, first, the human cranium, bones, and works of art which have been found more than a hundred feet deep in the gold-bearing gravels of California, associated with abundant vegetable remains of extinct species, and overlaid by four successive lava streams from long extinct volcanoes. The other case is that of rude stone implements discovered by a geologist of the Indian Survey in Burma in deposits which are admitted to be of at least Pliocene age. In both these cases the evidence is disputed by some geologists, who seem to think that there is something unscientific, or even wrong, in admitting evidence that would prove the Pliocene age of any other animal to be equally valid in the case of man. There is assumed to be a great improbability of his existence earlier than the very end of the Tertiary epoch. But all the indications drawn from his relations to the anthropoid apes point to an origin far back in Tertiary time. For each one of the great apes—the gorilla, the chimpanzee, the orang, and even the gibbon—resemble man in certain features more than do their allies, while in other points they are less like him. Now, if man has been developed from a lower animal form, we must seek his ancestors not in the direct line between him and any of the apes, but in a line toward a common ancestor to them all; and this common ancestor must certainly date back to the early part of the Tertiary epoch, because in the Miocene period anthropoid apes not very different from living forms have been found fossil.

There is therefore no improbability whatever in the existence of man in the later portions of the Tertiary period, and we have no right, scientifically, to treat any evidence for his existence in any other way than the evidence for the existence of other animal types.

It has been argued by some writers that, as no other living species of mammal goes back farther than the Newer Pliocene,

therefore man is probably no older. But it is forgotten that the difference of man from the apes is not only specific but at least of generic or of family rank, while some naturalists place him even in a separate order of mammalia. Besides the erect posture and free hands, with all the details of anatomical structure which these peculiarities imply, the great development of his brain pre-eminently distinguishes him. We may suppose, therefore, that when he had reached the erect form, and possessed all the external appearance of man, his brain still remained undeveloped, and the time occupied by this development was not improbably equal to that required for the specific modification of the lower mammalia. It is often forgotten that so soon as man used fire and made weapons, all further useful modification would be in the direction of increased brain power, by which he was able to succeed both in his struggle against the elements and with the lower animals. There is therefore no improbability in finding the remains or the implements of a low type of man in the early Pliocene period.

The certainty that man coexisted with many now extinct animals, and the probability of our discovering his remains in undoubted Tertiary strata, constitute an immense advance on the knowledge and beliefs of our forefathers, and must therefore rank among the prominent features in the scientific progress of the nineteenth century.

GEOLOGY

Coal

By ELISHA GRAY

LONG ago, some man made the discovery that what we now call coal would burn and produce light and warmth. Who he was or how long ago he lived we do not know, but as all earthly things have a beginning, we know that such a man did live and that the discovery that coal would burn was made. Coal, in the sense that we use the word here, is not mentioned in the Scriptures. According to some authorities, coal was used in England as early as the ninth century. It is recorded that in 1259 King Henry III. granted a privilege to certain parties to mine coal at Newcastle. It is further stated that seven years after this time coal became an article of export. In 1306, coal was so generally used in London that a petition was sent to Parliament to have the use of it suppressed on the ground that it was a nuisance. Coal was used in Belgium, however, about 1200. There is a tradition that a blacksmith first used it in Liège as fuel. It was first used for manufacturing purposes about 1713.

Coal is found laid down in great veins, varying in thickness, in various parts of the world in the upper strata of the Paleozoic era. The age in which it was formed is called by geologists the Carboniferous (coal-bearing) age.

Before going on to account for the deposits of coal, let us stop a moment and consider what it is. Chemists tell us that coal is constructed chiefly of carbon, compounded with oxygen, hydrogen, and nitrogen. There are many varieties, but all may be classified under two general headings—bituminous and

anthracite. Bituminous coal contains a large amount of a tarry substance, a kind of mineral pitch or bitumen, which burns with a brilliant flame and a black sooty smoke, exceedingly rich in carbon. Anthracite coal is hard and stone-like in its texture, burning with scarcely any flame and no smoke. It produces a fire of intense heat when it is once ignited. There is another form of coal called cannel coal, which is a corruption of "candle coal," so called because a piece of this kind of coal when ignited will burn like a match or pine knot and give light like a candle. This is the richest of all the coal deposits in gases that are set free by heat, and for this reason is extensively used in the manufacture of what is commonly called coal gas. England produces a large amount of cannel coal, as well as another variety of bituminous coal, which latter, however, does not burn with such a black smoke as the coal found in the Ohio valley and the Western States of America. East of the Alleghany Mountains there is a region of anthracite coal that is very extensively worked and finds great favor in all parts of the country as fuel for domestic heating, especially on account of its great cleanliness.

All of the coal beds have a common origin, and the difference in the quality of coal found in different parts of the country is due to many circumstances, some of which have never been explained. There is indisputable proof, however, that all coal beds are of vegetable origin. Geologists tell us that these coal beds were formed during an age before the earth had cooled down to the temperature that it has at the present time —an age when vegetation was forced by the internal heat of the earth, instead of having to receive all its warmth from the sun's rays as we do now. Some of our readers are familiar with what is commonly termed a hot-bed. A hot-bed is made by putting soil on top of substances that will ferment and create heat underneath the soil. This heat from beneath will force vegetation and cause a much larger growth than there will be if left to the sun's rays alone. During the carboniferous age the earth was a great hot-bed.

The fossils of trees and plants, as well as reptiles, that we find in the great coal measures of the world, show that they

were of large tropical growth, and this is shown not only in the temperate zone, but in the zone farther north. For ages and ages this rank growth of vegetation grew up and fell down until a great layer of vegetable matter was formed, which at a later time was covered over by other strata of varied earth material, so that these great layers of vegetable formation were hermetically sealed and pressed down by an enormous weight that increased as time went on. The formation of coal may be studied even at this day (for it is now going on) by visiting and examining the great peat beds that are found in various parts of the world. It is well known that peat is used as a fuel by many people, especially the peasantry of the old countries. If peat is pressed to a sufficient degree of hardness it burns in a manner not unlike some forms of coal. Peat is a vegetable formation and has been formed by the rank growth of various kinds of vegetation in swampy places. Of course, it lacks the purity of the coal that was formed during the carboniferous age, because of the much slower growth of vegetation now than during that time, and the opportunity that peat bogs offer for an intermixture of earthy with the vegetable matter. The fact that we find the imprint of trees and ferns and other vegetable growth of tropical varieties, as well as the fossils of reptiles, imbedded in the coal measures, proves that at one time this stratum was at the land surface of the earth. We also find that all the formations of the Secondary and Tertiary periods are on top of the coal—and this shows that after the age of rank vegetable growth there was a sinking of the earth in many places far down into the ocean—so that vast layers of rock formed on top of these beds of vegetable matter. In England great chalk beds crop out in cliffs on the southern coast, and these chalk rocks are made up largely of the shells of marine animals. London stands on a chalk bed, from six hundred to eight hundred feet thick. Indeed, England has been poetically called Albion, White-land, from this appearance of her coast.

All of the great chalk beds were formed ages after the coal beds, as the latter are found in the upper strata of the Paleozoic period.

A study of these strata will show that there are many layers

of coal strata varying in thickness and separated by layers of shale and sandstone.

From the position that the coal measures occupy, being entirely under the Secondary and Tertiary formations, it will be observed that they are very old. If we should examine a piece of ordinary bituminous coal we shoud find that there are lines of cleavage in it parallel to each other, and that it is an easy matter to separate the lump on these lines. If we examine the outcrop of a coal bed we shall find that these lines of cleavage are horizontal. This indicates that the great bulk of vegetable matter of which the coal formation is made up has been subjected to tremendous pressure during a long period of time. If we further examine the structure of a body of coal we find the impressions of limbs and branches as well as the leaves of trees and various kinds of plants. We shall further find that these impressions lie in a plane in the same direction as the line of cleavage. This is a point to be remembered, as it helps to explain the nature and structure of other formations than those of coal. Not only are leaves and branches of vegetable matter found, but also fossils of reptiles, such as live on the land. Sometimes there is found the fossil of a great tree trunk standing in an erect position, with its roots running down into the rock below the coal bed, while the trunk extends upward entirely through the coal and high up into the other strata. All of these facts lead us to the firm conclusion that when the trees were grown that formed these beds, they were above the surface of the ocean. This, taken in connection with the fact that the vegetable fossils that are found indicate a tropical growth of great size, leads to the conclusion that the climate at the time these coal measures were formed was much warmer than it is now.

As already remarked, this extra warmth came from the earth itself before it had cooled down to its present temperature, rather than from the heat of the sun. There is nothing inconsistent in the thought that the sun may have been warmer in a former age than now. We may conceive that the earliest coal formations took place when the land stood above the surface of the water, and that the conditions were favorable for a

rapid and luxuriant growth of vegetation; after this had gone on for a very long period of time, by some convulsion of nature the land surface was submerged under the ocean, when other mineral substances were deposited on top of this layer of vegetable growth, which hardened into a rock formation. At a later period the earth was again elevated above the surface of the water and the same process of growth and decay was repeated. These oscillations of the earth up and down occurred at enormously long intervals, until all of the various coal strata with their intermediate formations were completed. After this we must suppose that the whole was submerged to a great depth and for a very long period of time, because of the great number and various kinds of rock formations laid down by water that lie on top of the coal measures. This tremendous weight, as it was gradually builded up, subjected these vegetable strata to an inconceivable pressure. In some places this pressure was much greater than in others, which undoubtedly is one of the reasons why we find such differences in the structure and quality of coal. There were, no doubt, many other reasons for differences, one of them being the character of the vegetable growth out of which they were formed. Again, in some parts of the world these coal strata may have been subjected to a considerable degree of heat, which would change the structure of the formation, and in some cases drive off the volatile gases. One can easily imagine that heat was thus a factor in the formation of what is known as anthracite coal, so much less gaseous than the bituminous kinds. The anthracite beds seem to be denser and of a more homogeneous character. The lines of cleavage are not so prominent, but there are the same evidences of vegetable origin that we find in the bituminous formations.

It will be seen from what has gone before that coal was first wood. But wood is a product of sunshine. Thus the sun was the architect and builder of the trees and plants that were finally hermetically sealed under the great earth strata. The sun gathered up the material and set in play the forces which made the chemical combinations of the various elements in nature that enter into vegetable growth.

After the lapse of untold ages of time, these great beds of stored-up sun-energy were discovered by man and their contents were dragged out to the earth's surface, to warm our houses, to drive the machinery of our factories, to send the locomotives flying across the continents and the steamships over the oceans. So important has this article become that if any one nation could control the output it would be able to paralyze all the navies and the manufacturing of the world.

If the coal of the world should become exhausted we should be confronted with a great problem. Fortunately for us, this is a problem that will have to be solved by the people of some future age, as the growth of wood will scarcely keep pace with the consumption of fuel. By that time the genius of man will have devised an economical means of storing the energy of the sunbeams directly for purposes of heat, light, and power.

GEOLOGY

On a Piece of Chalk

By T. H. HUXLEY

IF a well were to be sunk at our feet in the midst of the English city of Norwich, the diggers would very soon find themselves at work in that white substance almost too soft to be called rock, with which we are all familiar as "chalk."

Not only here, but over the whole county of Norfolk, the well-sinker might carry his shaft down many hundred feet without coming to the end of the chalk; and, on the sea-coast, where the waves have pared away the face of the land which breasts them, the scarped faces of the high cliffs are often wholly formed of the same material. Northward, the chalk may be followed as far as Yorkshire; on the south coast it appears abruptly in the picturesque western bays of Dorset, and breaks into the Needles of the Isle of Wight; while on the shores of Kent it supplies that long line of white cliffs to which England owes her name of Albion.

Were the thin soil which covers it all washed away, a curved band of white chalk, here broader and there narrower, might be followed diagonally across England from Lulworth in Dorset, to Flamborough Head in Yorkshire—a distance of over two hundred and eighty miles as the crow flies.

From this band to the North Sea, on the east, and the Channel, on the south, the chalk is largely hidden by other deposits; but, except in the Weald of Kent and Sussex, it enters into the very foundation of all the southeastern counties.

Attaining, as it does in some places, a thickness more of

than a thousand feet, the English chalk must be admitted to be a mass of considerable magnitude. Nevertheless, it covers but an insignificant portion of the whole area occupied by the chalk formation of the globe, which has precisely the same general character as ours, and is found in detached patches, some less, and others more extensive, than the English.

Chalk occurs in Northwest Ireland; it stretches over a large part of France—the chalk which underlies Paris being, in fact, a continuation of that of the London basin; it runs through Denmark and Central Europe, and extends southward to North Africa; while eastward, it appears in the Crimea and in Syria, and may be traced as far as the shores of the Sea of Aral, in Central Asia.

If all the points at which true chalk occurs were circumscribed, they would lie within an irregular oval about three thousand miles in long diameter—the area of which would be as great as that of Europe, and would many times exceed that of the largest existing inland sea—the Mediterranean.

Thus the chalk is no unimportant element in the masonry of the earth's crust, and it impresses a peculiar stamp, varying with the conditions to which it is exposed, on the scenery of the districts in which it occurs. The undulating downs and rounded coombs, covered with sweet-grassed turf, of our inland chalk country, have a peacefully domestic and mutton-suggesting prettiness, but can hardly be called either grand or beautiful. But on our southern coasts, the wall-sided cliffs, many hundred feet high, with vast needles and pinnacles standing out in the sea, sharp and solitary enough to serve as perches for the wary cormorant, confer a wonderful beauty and grandeur upon the chalk headlands. And in the East, chalk has its share in the formation of some of the most venerable of mountain ranges, such as the Lebanon.

What is this widespread component of the surface of the earth? and whence did it come?

You may think this no very hopeful inquiry. You may not unnaturally suppose that the attempt to solve such problems as these can lead to no result, save that of entangling the

inquirer in vague speculations, incapable of refutation and of verification.

If such were really the case, I should have selected some other subject than "a piece of chalk" for my discourse. But, in truth, after much deliberation, I have been unable to think of any topic which would so well enable me to lead you to see how solid is the foundation upon which some of the most startling conclusions of physical science rest.

A great chapter of the history of the world is written in the chalk. Few passages in the history of man can be supported by such an overwhelming mass of direct and indirect evidence as that which testifies to the truth of the fragment of the history of the globe, which I hope to enable you to read, with your own eyes, to-night.

Let me add, that few chapters of human history have a more profound significance for ourselves. I weigh my words well when I assert, that the man who should know the true history of the bit of chalk which every carpenter carries about in his breeches' pocket, though ignorant of all other history, is likely, if he will think his knowledge out to its ultimate results, to have a truer, and therefore a better, conception of this wonderful universe, and of man's relation to it, than the most learned student who is deep-read in the records of humanity and ignorant of those of nature.

The language of the chalk is not hard to learn, not nearly so hard as Latin, if you only want to get at the broad features of the story it has to tell; and I propose that we now set to work to spell that story out together.

We all know that if we "burn" chalk, the result is quicklime. Chalk, in fact, is a compound of carbonic acid gas and lime; and when you make it very hot, the carbonic acid flies away and the lime is left.

By this method of procedure we see the lime, but we do not see the carbonic acid. If, on the other hand, you were to powder a little chalk and drop it into a good deal of strong vinegar, there would be a great bubbling and fizzing, and finally a clear liquid, in which no sign of chalk would appear. Here you see the carbonic acid in the bubbles; the lime, dissolved in the

THOMAS H. HUXLEY.

vinegar, vanishes from sight. There are a great many other ways of showing that chalk is essentially nothing but carbonic acid and quicklime. Chemists enunciate the result of all the experiments which prove this, by stating that chalk is almost wholly composed of "carbonate of lime."

It is desirable for us to start from the knowledge of this fact, though it may not seem to help us very far toward what we seek. For carbonate of lime is a widely spread substance, and is met with under very various conditions. All sorts of limestones are composed of more or less pure carbonate of lime. The crust which is often deposited by waters which have drained through limestone rocks, in the form of what are called stalagmites and stalactites, is carbonate of lime. Or, to take a more familiar example, the fur on the inside of a tea-kettle is carbonate of lime; and, for anything chemistry tells us to the contrary, the chalk might be a kind of gigantic fur upon the bottom of the earth-kettle, which is kept pretty hot below.

Let us try another method of making the chalk tell us its own history. To the unassisted eye chalk looks simply like a very loose and open kind of stone. But it is possible to grind a slice of chalk down so thin that you can see through it—until it is thin enough, in fact, to be examined with any magnifying power that may be thought desirable A thin slice of the fur of a kettle might be made in the same way. If it were examined microscopically, it would show itself to be a more or less distinctly laminated mineral substance, and nothing more.

But the slice of chalk presents a totally different appearance when placed under the microscope. The general mass of it is made up of very minute granules; but imbedded in this matrix are innumerable bodies, some smaller and some larger, but, on a rough average, not more than a hundredth of an inch in diameter, having a well-defined shape and structure. A cubic inch of some specimens of chalk may contain hundreds of thousands of these bodies, compacted together with incalculable millions of the granules.

The examination of a transparent slice gives a good notion of the manner in which the components of the chalk are

arranged, and of their relative proportions. But, by rubbing up some chalk with a brush in water and then pouring off the milky fluid, so as to obtain sediments of different degrees of fineness, the granules and the minute rounded bodies may be pretty well separated from one another, and submitted to microscopic examination, either as opaque or as transparent objects. By combining the views obtained in these various methods, each of the rounded bodies may be proved to be a beautifully constructed calcareous fabric, made up of a number of chambers, communicating freely with one another. The chambered bodies are of various forms. One of the commonest is something like a badly grown raspberry, being formed of a number of nearly globular chambers of different sizes congregated together. It is called Globigerina, and some specimens of chalk consist of little else than Globigerinæ and granules.

Let us fix our attention upon the Globigerina. If we can learn what it is and what are the conditions of its existence, we shall see our way to the origin and past history of the chalk.

A suggestion which may naturally enough present itself is, that these curious bodies are the result of some process of aggregation which has taken place in the carbonate of lime; that, just as in winter, the rime on our windows simulates the most delicate and elegantly arborescent foliage—proving that the mere mineral matter may, under certain conditions, assume the outward form of organic bodies—so this mineral substance, carbonate of lime, hidden away in the bowels of the earth, has taken the shape of these chambered bodies. I am not raising a merely fanciful and unreal objection. Very learned men, in former days, have even entertained the notion that all the formed things found in rocks are of this nature; and if no such conception is at present held to be admissible, it is because long and varied experience has now shown that mineral matter never does assume the form and structure we find in fossils. If any one were to try to persuade you that an oyster-shell (which is also chiefly composed of carbonate of lime) had crystallized out of sea-water, I suppose you would laugh at the absurdity. Your laughter would be justified by the fact that all

experience tends to show that oyster-shells are formed by the agency of oysters, and in no other way. And if there were no better reasons, we should be justified, on like grounds, in believing that Globigerina is not the product of anything but vital activity.

Happily, however, better evidence in proof of the organic nature of the Globigerinæ than that of analogy is forthcoming. It so happens that calcareous skeletons, exactly similar to the Globigerinæ of the chalk, are being formed, at the present moment, by minute living creatures, which flourish in multitudes, literally more numerous than the sands of the seashore, over a large extent of that part of the earth's surface which is covered by the ocean.

The history of the discovery of these living Globigerinæ, and of the part which they play in rock-building, is singular enough. It is a discovery which, like others of no less scientific importance, has arisen, incidentally, out of work devoted to very different and exceedingly practical interests.

When men first took to the sea, they speedily learned to look out for shoals and rocks; and the more the burden of their ships increased, the more imperatively necessary it became for sailors to ascertain with precision the depth of the waters they traversed. Out of this necessity grew the use of the lead and sounding-line; and, ultimately, marine surveying, which is the recording of the form of coasts and of the depth of the sea, as ascertained by the sounding-lead, upon charts.

At the same time, it became desirable to ascertain and to indicate the nature of the sea-bottom, since this circumstance greatly affects its goodness as holding ground for anchors. Some ingenious tar, whose name deserves a better fate than the oblivion into which it has fallen, attained this object by "arming" the bottom of the lead with a lump of grease, to which more or less of the sand or mud, or broken shells, as the case might be, adhered, and was brought to the surface. But, however well adapted such an apparatus might be for rough nautical purposes, scientific accuracy could not be expected from the armed lead, and to remedy its defects (especially when applied to sounding in great depths) Lieutenant Brooke, of the

American Navy, some years ago invented a most ingenious machine, by which a considerable portion of the superficial layer of the sea-bottom can be scooped out and brought up from any depth to which the lead descends.

In 1853, Lieutenant Brooke obtained mud from the bottom of the North Atlantic, between Newfoundland and the Azores, at a depth of more than 10,000 feet, or two miles, by the help of this sounding apparatus. The specimens were sent for examination to Ehrenberg of Berlin, and to Bailey of West Point, and those able microscopists found that this deep-sea mud was almost entirely composed of the skeletons of living organisms—the greater proportion of these being just like the Globigerinæ already known to occur in chalk.

Thus far, the work had been carried on simply in the interests of science, but Lieutenant Brooke's method of sounding acquired a high commercial value when the enterprise of laying down the telegraph-cable between this country and the United States was undertaken. For it became a matter of immense importance to know, not only the depth of the sea over the whole line along which the cable was to be laid, but the exact nature of the bottom, so as to guard against chances of cutting or fraying the strands of that costly rope. The Admiralty consequently ordered Captain Dayman, an old friend and shipmate of mine, to ascertain the depth over the whole line of the cable, and to bring back specimens of the bottom. In former days, such a command as this might have sounded very much like one of the impossible things which the young prince in the fairy tales is ordered to do before he can obtain the hand of the princess. However, in the months of June and July, 1857, my friend performed the task assigned to him with great expedition and precision, without, so far as I know, having met with any reward of that kind. The specimens of Atlantic mud which he procured were sent to me to be examined and reported upon.

The result of all these operations is, that we know the contours and the nature of the surface-soil covered by the North Atlantic, for a distance of 1,700 miles from east to west, as well as we know that of any part of the dry land.

It is a prodigious plain—one of the widest and most even plains in the world. If the sea were drained off, you might drive a wagon all the way from Valentia, on the west coast of Ireland, to Trinity Bay in Newfoundland. And, except upon one sharp incline about two hundred miles from Valentia, I am not quite sure that it would even be necessary to put the skid on, so gentle are the ascents and descents upon that long route. From Valentia the road would lie down-hill for about two hundred miles to the point at which the bottom is now covered by 1,700 fathoms of sea-water. Then would come the central plain, more than a thousand miles wide, the inequalities of the surface of which would be hardly perceptible, though the depth of water upon it now varies from 10,000 to 15,000 feet; and there are places in which Mont Blanc might be sunk without showing its peak above water. Beyond this, the ascent on the American side commences, and gradually leads, for about three hundred miles, to the Newfoundland shore.

Almost the whole of the bottom of this central plain (which extends for many hundred miles in a north and south direction) is covered by a fine mud, which, when brought to the surface, dries into a grayish white friable substance. You can write with this on a blackboard, if you are so inclined; and, to the eye, it is quite like very soft, grayish chalk. Examined chemically, it proves to be composed almost wholly of carbonate of lime; and if you make a section of it, in the same way as that of the piece of chalk was made, and view it with the microscope, it presents innumerable Globigerinæ embedded in a granular matrix.

Thus this deep-sea mud is substantially chalk. I say substantially, because there are a good many minor differences; but as these have no bearing on the question immediately before us—which is the nature of the Globigerinæ of the chalk—it is unnecessary to speak of them.

Globigerinæ of every size, from the smallest to the largest, are associated together in the Atlantic mud, and the chambers of many are filled by a soft animal matter. This soft substance is, in fact, the remains of the creature to which the Globigerina shell, or rather skeleton, owes its existence—and which is an

animal of the simplest imaginable description. It is, in fact, a mere particle of living jelly, without defined parts of any kind —without a mouth, nerves, muscles, or distinct organs, and only manifesting its vitality to ordinary observation by thrusting out and retracting from all parts of its surface long filamentous processes, which serve for arms and legs. Yet this amorphous particle, devoid of everything which, in the higher animals, we call organs, is capable of feeding, growing, and multiplying; of separating from the ocean the small proportion of carbonate of lime which is dissolved in sea-water; and of building up that substance into a skeleton for itself according to a pattern which can be imitated by no other known agency.

The notion that animals can live and flourish in the sea, at the vast depths from which apparently living Globigerinæ have been brought up, does not agree very well with our usual conceptions respecting the conditions of animal life; and it is not so absolutely impossible as it might at first appear to be, that the Globigerinæ of the Atlantic sea-bottom do not live and die where they are found.

As I have mentioned, the soundings from the great Atlantic plain are almost entirely made up of Globigerinæ, with the granules which have been mentioned, and some few other calcareous shells; but a small percentage of the chalky mud—perhaps at most some five per cent. of it—is of a different nature, and consists of shells and skeletons composed of silex, or pure flint. These siliceous bodies belong partly to the lowly vegetable organisms which are called Diatomaceæ, and partly to the minute and extremely simple animals termed Radiolaria. It is quite certain that these creatures do not live at the bottom of the ocean, but at its surface—where they may be obtained in prodigious numbers by the use of a properly constructed net. Hence it follows that these siliceous organisms, though they are not heavier than the lightest dust, must have fallen, in some cases, through 15,000 feet of water, before they reached their final resting-place on the ocean floor. And, considering how large a surface these bodies expose in proportion to their weight, it is probable that they occupy a great length of time

in making their burial journey from the surface of the Atlantic to the bottom.

But if the Radiolaria and Diatoms are thus rained upon the bottom of the sea, from the superficial layer of its waters in which they pass their lives, it is obviously possible that the Globigerinæ may be similarly derived; and if they were so, it would be much more easy to understand how they obtain their supply of food than it is at present. Nevertheless, the positive and negative evidence all points the other way. The skeletons of the full-grown, deep-sea Globigerinæ are so remarkably solid and heavy in proportion to their surface as to seem little fitted for floating; and, as a matter of fact, they are not to be found along with the Diatoms and Radiolaria, in the uppermost stratum of the open ocean.

It has been observed, again, that the abundance of Globigerinæ, in proportion to other organisms of like kind, increases with the depth of the sea; and that deep-water Globigerinæ are larger than those which live in the shallower parts of the sea; and such facts negative the supposition that these organisms have been swept by currents from the shallows into the deeps of the Atlantic.

It therefore seems to be hardly doubtful that these wonderful creatures live and die at the depths in which they are found.

However, the important points for us are, that the living Globigerinæ are exclusively marine animals, the skeletons of which abound at the bottom of deep seas; and that there is not a shadow of reason for believing that the habits of the Globigerinæ of the chalk differed from those of the existing species. But if this be true, there is no escaping the conclusion that the chalk itself is the dried mud of an ancient deep sea.

In working over the soundings collected by Captain Dayman, I was surprised to find that many of what I have called the "granules" of that mud were not, as one might have been tempted to think at first, the mere powder and waste of Globigerinæ, but that they had a definite form and size. I termed these bodies "*coccoliths*," and doubted their organic nature. Dr. Wallich verified my observation, and added the interesting discovery that, not infrequently, bodies similar to these

"coccoliths" were aggregated together into spheroids, which he termed "*coccospheres*." So far as we knew, these bodies, the nature of which is extremely puzzling and problematical, were peculiar to the Atlantic soundings.

But, a few years ago, Mr. Sorby, in making a careful examination of the chalk by means of thin sections and otherwise, observed, as Ehrenberg had done before him, that much of its granular basis possesses a definite form. Comparing these formed particles with those in the Atlantic soundings, he found the two to be identical; and thus proved that the chalk, like the soundings, contains these mysterious coccoliths and coccospheres. Here was a further and a most interesting confirmation, from internal evidence, of the essential identity of the chalk with modern deep-sea mud. Globigerinæ, coccoliths, and coccospheres are found as the chief constituents of both, and testify to the general similarity of the conditions under which both have been formed.

The evidence furnished by the hewing, facing, and superposition of the stones of the Pyramids, that these structures were built by men, has no greater weight than the evidence that the chalk was built by Globigerinæ; and the belief that those ancient pyramid-builders were terrestrial and air-breathing creatures like ourselves, is not better based than the conviction that the chalk-makers lived in the sea.

But as our belief in the building of the Pyramids by men is not only grounded on the internal evidence afforded by these structures, but gathers strength from multitudinous collateral proofs, and is clinched by the total absence of any reason for a contrary belief; so the evidence drawn from the Globigerinæ that the chalk is an ancient sea-bottom, is fortified by innumerable independent lines of evidence; and our belief in the truth of the conclusion to which all positive testimony tends, receives the like negative justification from the fact that no other hypothesis has a shadow of foundation.

It may be worth while briefly to consider a few of these collateral proofs that the chalk was deposited at the bottom of the sea.

The great mass of the chalk is composed, as we have seen,

of the skeletons of Globigerinæ, and other simple organisms, imbedded in granular matter. Here and there, however, this hardened mud of the ancient sea reveals the remains of higher animals which have lived and died, and left their hard parts in the mud, just as the oysters die and leave their shells behind them in the mud of the present seas.

There are, at the present day, certain groups of animals which are never found in fresh waters, being unable to live anywhere but in the sea. Such are the corals; those corallines which are called Polyzoa; those creatures which fabricate the lamp-shells, and are called Brachiopoda; the pearly Nautilus, and all animals allied to it; and all the forms of sea-urchins and star-fishes.

Not only are all these creatures confined to salt water at the present day, but, so far as our records of the past go, the conditions of their existence have been the same: hence, their occurrence in any deposit is as strong evidence as can be obtained, that that deposit was formed in the sea. Now, the remains of animals of all the kinds which have been enumerated occur in the chalk, in greater or less abundance; while not one of those forms of shell-fish which are characteristic of fresh water has yet been observed in it.

When we consider that the remains of more than three thousand distinct species of aquatic animals have been discovered among the fossils of the chalk, that the great majority of them are of such forms as are now met with only in the sea, and that there is no reason to believe that any one of them inhabited fresh water—the collateral evidence that the chalk represents an ancient sea-bottom acquires as great force as the proof derived from the nature of the chalk itself. I think you will now allow that I did not overstate my case when I asserted that we have as strong grounds for believing that all the vast area of dry land at present occupied by the chalk was once at the bottom of the sea, as we have for any matter of history whatever; while there is no justification for any other belief.

No less certain is it that the time during which the countries we now call southeast England, France, Germany, Poland,

Russia, Egypt, Arabia, Syria, were more or less completely covered by a deep sea, was of considerable duration.

We have already seen that the chalk is, in places, more than a thousand feet thick. I think you will agree with me that it must have taken some time for the skeletons of the animalcules of a hundredth of an inch in diameter to heap up such a mass as that. I have said that throughout the thickness of the chalk the remains of other animals are scattered. These remains are often in the most exquisite state of preservation. The valves of the shell-fishes are commonly adherent; the long spines of some of the sea-urchins, which would be detached by the smallest jar, often remain in their places. In a word, it is certain that these animals have lived and died when the place which they now occupy was the surface of as much of the chalk as had then been deposited; and that each has been covered up by the layer of Globigerina mud, upon which the creatures imbedded a little higher up have, in like manner, lived and died. But some of these remains prove the existence of reptiles of vast size in the chalk sea. These lived their time, and had their ancestors and descendants, which assuredly implies time, reptiles being of slow growth. There is more curious evidence, again, that the process of covering up, or, in other words, the deposit of Globigerina skeletons, did not go on very fast. It is demonstrable that an animal of the cretaceous sea might die, that its skeleton might lie uncovered upon the sea-bottom long enough to lose all its outward coverings and appendages by putrefaction; and that, after this had happened, another animal might attach itself to the dead and naked skeleton, might grow to maturity, and might itself die before the calcareous mud had buried the whole.

Cases of this kind are admirably described by Sir Charles Lyell. He speaks of the frequency with which geologists find in the chalk a fossilized sea-urchin to which is attached the lower valve of a Crania. This is a kind of shell-fish, with a shell composed of two pieces, of which, as in the oyster, one is fixed and the other free.

"The upper valve is almost invariably wanting, though occasionally found in a perfect state of preservation in the white

chalk at some distance. In this case, we see clearly that the sea-urchin first lived from youth to age, then died and lost its spines, which were carried away. Then the young Crania adhered to the bared shell, grew and perished in its turn; after which, the upper valve was separated from the lower, before the Echinus became enveloped in chalky mud."

A specimen in the Museum of Practical Geology, in London, still further prolongs the period which must have elapsed between the death of the sea-urchin and its burial by the Globigerinæ. For the outward face of the valve of a Crania, which is attached to a sea-urchin (Micraster), is itself overrun by an incrusting coralline, which spreads thence over more or less of the surface of the sea-urchin. It follows that, after the upper valve of the Crania fell off, the surface of the attached valve must have remained exposed long enough to allow of the growth of the whole coralline, since corallines do not live imbedded in the mud.

The progress of knowledge may, one day, enable us to deduce from such facts as these the maximum rate at which the chalk can have accumulated, and thus to arrive at the minimum duration of the chalk period. Suppose that the valve of the Crania upon which a coralline has fixed itself in the way just described is so attached to the sea-urchin that no part of it is more than an inch above the face upon which the sea-urchin rests. Then, as the coralline could not have fixed itself if the Crania had been covered up with chalk-mud, and could not have lived had itself been so covered, it follows that an inch of chalk mud could not have accumulated within the time between the death and decay of the soft parts of the sea-urchin and the growth of the coralline to the full size which it has attained. If the decay of the soft parts of the sea-urchin; the attachment, growth to maturity, and decay of the Crania; and the subsequent attachment and growth of the coralline, took a year (which is a low estimate enough), the accumulation of the inch of chalk must have taken more than a year: and the deposit of a thousand feet of chalk must, consequently, have taken more than twelve thousand years.

The foundation of all this calculation is, of course, a knowl-

edge of the length of time the Crania and the coralline needed to attain their full size; and, on this head, precise knowledge is at present wanting. But there are circumstances which tend to show that nothing like an inch of chalk has accumulated during the life of a Crania; and, on any probable estimate of the length of that life, the chalk period must have had a much longer duration than that thus roughly assigned to it.

Thus, not only is it certain that the chalk is the mud of an ancient sea-bottom; but it is no less certain that the chalk sea existed during an extremely long period, though we may not be prepared to give a precise estimate of the length of that period in years. The relative duration is clear, though the absolute duration may not be definable. The attempt to affix any precise date to the period at which the chalk sea began or ended its existence, is baffled by difficulties of the same kind. But the relative age of the Cretaceous epoch may be determined with as great ease and certainty as the long duration of that epoch.

You will have heard of the interesting discoveries recently made, in various parts of Western Europe, of flint implements, obviously worked into shape by human hands, under circumstances which show conclusively that man is a very ancient denizen of these regions.

It has been proved that the old populations of Europe, whose existence has been revealed to us in this way, consisted of savages, such as the Esquimaux are now; that, in the country which is now France, they hunted the reindeer, and were familiar with the ways of the mammoth and the bison. The physical geography of France was in those days different from what it is now—the river Somme, for instance, having cut its bed a hundred feet deeper between that time and this; and it is probable that the climate was more like that of Canada or Siberia than that of Western Europe.

The existence of these people is forgotten even in the traditions of the oldest historical nations. The name and fame of them had utterly vanished until a few years back; and the amount of physical change which has been effected since their day renders it more than probable that, venerable as are some

of the historical nations, the workers of the chipped flints of Hoxne or of Amiens are to them, as they are to us, in point of antiquity.

But, if we assign to these hoar relics of long-vanished generations of men the greatest age that can possibly be claimed for them, they are not older than the drift, or bowlder clay, which, in comparison with the chalk, is but a very juvenile deposit. You need go no further than your own seaboard for evidence of this fact. At one of the most charming spots on the coast of Norfolk, Cromer, you will see the bowlder clay forming a vast mass, which lies upon the chalk, and must consequently have come into existence after it. Huge bowlders of chalk are, in fact, included in the clay, and have evidently been brought to the position they now occupy by the same agency as that which has planted blocks of syenite from Norway side by side with them.

The chalk, then, is certainly older than the bowlder clay. If you ask how much, I will again take you no further than the same spot upon your own coasts for evidence. I have spoken of the bowlder clay and drift as resting upon the chalk. That is not strictly true. Interposed between the chalk and the drift is a comparatively insignificant layer, containing vegetable matter. But that layer tells a wonderful history. It is full of stumps of trees standing as they grew. Fir-trees are there with their cones, and hazel-bushes with their nuts; there stand the stools of oak and yew trees, beeches and alders. Hence this stratum is appropriately called the "forest-bed."

It is obvious that the chalk must have been upheaved and converted into dry land before the timber trees could grow upon it. As the bolls of some of these trees are from two to three feet in diameter, it is no less clear that the dry land thus formed remained in the same condition for long ages. And not only do the remains of stately oaks and well-grown firs testify to the duration of this condition of things, but additional evidence to the same effect is afforded by the abundant remains of elephants, rhinoceroses, hippopotamuses, and other great wild beasts, which it has yielded to the zealous search of such men as the Rev. Mr. Gunn.

When you look at such a collection as he has formed, and bethink you that these elephantine bones did veritably carry their owners about, and these great grinders crunch, in the dark woods of which the forest-bed is now the only trace, it is impossible not to feel that they are as good evidence of the lapse of time as the annual rings of the tree-stumps.

Thus there is a writing upon the wall of cliffs at Cromer, and whoso runs may read it. It tells us, with an authority which cannot be impeached, that the ancient sea-bed of the chalk sea was raised up, and remained dry land, until it was covered with forest, stocked with the great game whose spoils have rejoiced your geologists. How long it remained in that condition cannot be said; but "the whirligig of time brought its revenges" in those days as in these. That dry land, with the bones and teeth of generations of long-lived elephants, hidden away among the gnarled roots and dry leaves of its ancient trees, sank gradually to the bottom of the icy sea, which covered it with huge masses of drift and bowlder clay. Sea-beasts, such as the walrus, now restricted to the extreme north, paddled about where birds had twittered among the topmost twigs of the fir-trees. How long this state of things endured we know not, but at last it came to an end. The upheaved glacial mud hardened into the soil of modern Norfolk. Forests grew once more, the wolf and the beaver replaced the reindeer and the elephant; and at length what we call the history of England dawned.

Thus you have, within the limits of your own county, proof that the chalk can justly claim a very much greater antiquity than even the oldest physical traces of mankind. But we may go further and demonstrate, by evidence of the same authority as that which testifies to the existence of the father of men, that the chalk is vastly older than Adam himself.

The Book of Genesis informs us that Adam, immediately upon his creation, and before the appearance of Eve, was placed in the garden of Eden. The problem of the geographical position of Eden has greatly vexed the spirits of the learned in such matters, but there is one point respecting which, so far as I know, no commentator has ever raised a doubt. This is, that

of the four rivers which are said to run out of it, Euphrates and Hiddekel are identical with the rivers now known by the names of Euphrates and Tigris.

But the whole country in which these mighty rivers take their origin, and through which they run, is composed of rocks which are either of the same age as the chalk, or of later date. So that the chalk must not only have been formed, but, after its formation, the time required for the deposit of these later rocks, and for their upheaval into dry land, must have elapsed, before the smallest brook which feeds the swift stream of "the great river, the river of Babylon," began to flow.

Thus, evidence which cannot be rebutted, and which need not be strengthened, though if time permitted I might indefinitely increase its quantity, compels you to believe that the earth, from the time of the chalk to the present day, has been the theater of a series of changes as vast in their amount as they were slow in their progress. The area on which we stand has been first sea and then land, for at least four alternations; and has remained in each of these conditions for a period of great length.

Nor have these wonderful metamorphoses of sea into land, and of land into sea, been confined to one corner of England. During the Chalk period, or "Cretaceous epoch," not one of the present great physical features of the globe was in existence. Our great mountain ranges Pyrenees, Alps, Himalayas, Andes, have all been upheaved since the chalk was deposited, and the cretaceous sea flowed over the sites of Sinai and Ararat.

All this is certain, because rocks of cretaceous or still later date have shared in the elevatory movements which gave rise to these mountain chains; and may be found perched up, in some cases, many thousand feet high upon their flanks. And evidence of equal cogency demonstrates that, though in Norfolk the forest-bed rests directly upon the chalk, yet it does so, not because the period at which the forest grew immediately followed that at which the chalk was formed, but because an immense lapse of time, represented elsewhere by thousands of feet of rock, is not indicated at Cromer.

I must ask you to believe that there is no less conclusive proof that a still more prolonged succession of similar changes occurred before the chalk was deposited. Nor have we any reason to think that the first term in the series of these changes is known. The oldest sea-beds preserved to us are sands, and mud, and pebbles, the wear and tear of rocks which were formed in still older oceans.

But, great as is the magnitude of these physical changes of the world, they have been accompanied by a no less striking series of modifications in its living inhabitants.

All the great classes of animals, beasts of the field, fowls of the air, creeping things, and things which dwell in the waters, flourished upon the globe long ages before the chalk was deposited. Very few, however, if any, of these ancient forms of animal life were identical with those which now live. Certainly not one of the higher animals was of the same species as any of those now in existence. The beasts of the field, in the days before the chalk, were not our beasts of the field, nor the fowls of the air such as those which the eye of man has seen flying, unless his antiquity dates infinitely further back than we at present surmise. If we could be carried back into those times, we should be as one suddenly set down in Australia before it was colonized. We should see mammals, birds, reptiles, fishes, insects, snails, and the like, clearly recognizable as such, and yet not one of them would be just the same as those with which we are familiar, and many would be extremely different.

From that time to the present, the population of the world has undergone slow and gradual, but incessant, changes. There has been no grand catastrophe—no destroyer has swept away the forms of life of one period, and replaced them by a totally new creation; but one species has vanished and another has taken its place; creatures of one type of structure have diminished, those of another have increased, as time has passed on. And thus, while the differences between the living creatures of the time before the chalk and those of the present day appear startling, if placed side by side, we are led from one to the other by the most gradual progress, if we follow the course

of Nature through the whole series of those relics of her operations which she has left behind.

And it is by the population of the chalk sea that the ancient and the modern inhabitants of the world are most completely connected. The groups which are dying out flourish, side by side, with the groups which are now the dominant forms of life.

Thus the chalk contains remains of those flying and swimming reptiles, the pterodactyl, the ichthyosaurus, and the plesiosaurus, which are found in no later deposits, but abounded in preceding ages. The chambered shells called ammonites and belemnites, which are so characteristic of the period preceding the cretaceous, in like manner die with it.

But, among these fading reminders of a previous state of things, are some very modern forms of life, looking like Yankee peddlers among a tribe of red Indians. Crocodiles of modern type appear; bony fishes, many of them very similar to existing species, almost supplant the forms of fish which predominate in more ancient seas; and many kinds of living shell-fish first become known to us in the chalk. The vegetation acquires a modern aspect. A few living animals are not even distinguishable as species from those which existed at that remote epoch. The Globigerina of the present day, for example, is not different specifically from that of the chalk; and the same may be said of many other Foraminifera. I think it probable that critical and unprejudiced examination will show that more than one species of much higher animals have had a similar longevity; but the only example which I can at present give confidently is the snake's-head lamp-shell (*Terebratulina caput serpentis*), which lives in our English seas and abounded (as *Terebratulina striata* of authors) in the chalk.

The longest line of human ancestry must hide its diminished head before the pedigree of this insignificant shell-fish. We Englishmen are proud to have an ancestor who was present at the battle of Hastings. The ancestors of *Terebratulina caput serpentis* may have been present at a battle of Ichthyosauria in that part of the sea which, when the chalk was forming, flowed over the site of Hastings. While all around has changed, this Terebratulina has peacefully propagated its species from gener-

ation to generation, and stands to this day as a living testimony to the continuity of the present with the past history of the globe.

Up to this moment I have stated, so far as I know, nothing but well-authenticated facts, and the immediate conclusions which they force upon the mind.

But the mind is so constituted that it does not willingly rest in facts and immediate causes, but seeks always after a knowledge of the remoter links in the chain of causation.

Taking the many changes of any given spot of the earth's surface, from sea to land, and from land to sea, as an established fact, we cannot refrain from asking ourselves how these changes have occurred. And when we have explained them—as they must be explained—by the alternate slow movements of elevation and depression which have affected the crusts of the earth, we go still further back, and ask, Why these movements?

I am not certain that any one can give you a satisfactory answer to that question. Assuredly I cannot. All that can be said for certain is, that such movements are part of the ordinary course of nature, inasmuch as they are going on at the present time. Direct proof may be given, that some parts of the land of the northern hemisphere are at this moment insensibly rising and others insensibly sinking; and there is indirect but perfectly satisfactory proof, that an enormous area now covered by the Pacific has been deepened thousands of feet since the present inhabitants of that sea came into existence.

Thus there is not a shadow of a reason for believing that the physical changes of the globe, in past times, have been effected by other than natural causes.

Is there any more reason for believing that the concomitant modifications in the forms of the living inhabitants of the globe have been brought about in any other way?

Before attempting to answer this question, let us try to form a distinct mental picture of what has happened in some special case.

The crocodiles are animals which, as a group, have a very

vast antiquity. They abounded ages before the chalk was deposited; they throng the rivers in warm climates at the present day. There is a difference in the form of the joints of the backbone, and in some minor particulars, between the crocodiles of the present epoch and those which lived before the chalk; but, in the Cretaceous epoch, as I have already mentioned, the crocodiles had assumed the modern type of structure. Notwithstanding this, the crocodiles of the chalk are not identically the same as those which lived in the times called "older tertiary," which succeeded the Cretaceous epoch; and the crocodiles of the older tertiaries are not identical with those of the newer tertiaries, nor are these identical with existing forms. I leave open the question whether particular species may have lived on from epoch to epoch. But each epoch has had its peculiar crocodiles; though all, since the chalk, have belonged to the modern type, and differ simply in their proportions and in such structural particulars as are discernible only to trained eyes.

How is the existence of this long succession of different species of crocodiles to be accounted for?

Only two suppositions seem to be open to us—either each species of crocodile has been specially created, or it has arisen out of some preëxisting form by the operation of natural causes.

Choose your hypothesis; I have chosen mine. I can find no warranty for believing in the distinct creation of a score of successive species of crocodiles in the course of countless ages of time. Science gives no countenance to such a wild fancy; nor can even the perverse ingenuity of a commentator pretend to discover this sense, in the simple words in which the writer of Genesis records the proceeding of the fifth and sixth days of the Creation.

On the other hand, I see no good reason for doubting the necessary alternative, that all these varied species have been evolved from preëxisting crocodilian forms by the operation of causes as completely a part of the common order of nature as those which have effected the changes of the inorganic world.

Few will venture to affirm that the reasoning which applies to crocodiles loses its force among other animals or among

plants. If one series of species has come into existence by the operation of natural causes, it seems folly to deny that all may have arisen in the same way.

A small beginning has led us to a great ending. If I were to put the bit of chalk with which we started into the hot but obscure flame of burning hydrogen, it would presently shine like the sun. It seems to me that this physical metamorphosis is no false image of what has been the result of our subjecting it to a jet of fervent, though nowise brilliant, thought to-night. It has become luminous, and its clear rays, penetrating the abyss of the remote past, have brought within our ken some stages of the evolution of the earth. And in the shifting "without haste, but without rest," of the land and sea, as in the endless variation of the forms assumed by living beings, we have observed nothing but the natural product of the forces originally possessed by the substance of the universe.

GEOLOGY

Volcanoes

By L. AGASSIZ

FIRST-BORN among the continents, though so much later in culture and civilization than some of more recent birth, America, so far as her physical history is concerned, has been falsely denominated the *New World*. Hers was the first dry land lifted out of the waters, hers the first shore washed by the ocean that enveloped all the earth beside; and while Europe was represented only by islands rising here and there above the sea, America already stretched an unbroken line of land from Nova Scotia to the Far West.

In the present state of our knowledge, our conclusions respecting the beginning of the earth's history, the way in which it took form and shape as a distinct, separate planet, must, of course, be very vague and hypothetical. Yet the progress of science is so rapidly reconstructing the past that we may hope to solve even this problem; and to one who looks upon man's appearance upon the earth as the crowning work in a succession of creative acts, all of which have had relation to his coming in the end, it will not seem strange that he should at last be allowed to understand a history which was but the introduction to his own existence. It is my belief that not only the future, but the past also, is the inheritance of man, and that we shall yet conquer our lost birthright.

Even now our knowledge carries us far enough to warrant the assertion that there was a time when our earth was in a state of igneous fusion, when no ocean bathed it and no atmosphere surrounded it, when no wind blew over it and no rain fell

upon it, but an intense heat held all its materials in solution. In those days the rocks which are now the very bones and sinews of our mother Earth—her granites, her porphyries, her basalts, her syenites—were melted into a liquid mass. As I am writing for the unscientific reader, who may not be familiar with the facts through which these inferences have been reached, I will answer here a question which, were we talking together, he might naturally ask in a somewhat skeptical tone. How do you know that this state of things ever existed, and, supposing that the solid materials of which our earth consists were ever in a liquid condition, what right have you to infer that this condition was caused by the action of heat upon them? I answer, Because it is acting upon them still; because the earth we tread is but a thin crust floating on a liquid sea of molten materials; because the agencies that were at work then are at work now, and the present is the logical sequence of the past. From artesian wells, from mines, from geysers, from hot springs, a mass of facts has been collected, proving incontestably the heated condition of all substances at a certain depth below the earth's surface; and if we need more positive evidence, we have it in the fiery eruptions that even now bear fearful testimony to the molten ocean seething within the globe and forcing its way out from time to time. The modern progress of geology has led us by successive and perfectly connected steps back to a time when what is now only an occasional and rare phenomenon was the normal condition of our earth; when the internal fires were enclosed by an envelope so thin that it opposed but little resistance to their frequent outbreak, and they constantly forced themselves through this crust, pouring out melted materials that subsequently cooled and consolidated on its surface. So constant were these eruptions, and so slight was the resistance they encountered, that some portions of the earlier rock-deposits are perforated with numerous chimneys, narrow tunnels as it were, bored by the liquid masses that poured out through them and greatly modified their first condition.

The question at once suggests itself, How was even this thin crust formed? what should cause any solid envelope, how-

ever slight and filmy when compared to the whole bulk of the globe, to form upon the surface of such a liquid mass? At this point of the investigation the geologist must appeal to the astronomer; for in this vague and nebulous border-land, where the very rocks lose their outlines and flow into each other, not yet specialized into definite forms and substances—there the two sciences meet. Astronomy shows us our planet thrown off from the central mass of which it once formed a part, to move henceforth in an independent orbit of its own. That orbit, it tells us, passed through celestial spaces cold enough to chill this heated globe, and of course to consolidate it externally. We know, from the action of similar causes on a smaller scale and on comparatively insignificant objects immediately about us, what must have been the effect of this cooling process upon the heated mass of the globe. All substances when heated occupy more space than they do when cold. Water, which expands when freezing, is the only exception to this rule. The first effect of cooling the surface of our planet must have been to solidify it, and thus to form a film or crust over it. That crust would shrink as the cooling process went on; in consequence of the shrinking, wrinkles and folds would arise upon it, and here and there, where the tension was too great, cracks and fissures would be produced. In proportion as the surface cooled, the masses within would be affected by the change of temperature outside of them, and would consolidate internally also, the crust gradually thickening by this process.

But there was another element without the globe, equally powerful in building it up. Fire and water wrought together in this work, if not always harmoniously, at least with equal force and persistency. I have said that there was a time when no atmosphere surrounded the earth; but one of the first results of the cooling of its crust must have been the formation of an atmosphere, with all the phenomena connected with it—the rising of vapors, their condensation into clouds, the falling of rains, the gathering of waters upon its surface. Water is a very active agent of destruction, but it works over again the materials it pulls down or wears away, and builds them up anew in other forms. As soon as an ocean washed over the consoli-

dated crust of the globe, it would begin to abrade the surfaces upon which it moved, gradually loosening and detaching materials, to deposit them again as sand or mud or pebbles at its bottom in successive layers, one above another. Thus, in analyzing the crust of the globe, we find at once two kinds of rocks, the respective work of fire and water: the first poured out from the furnaces within, and cooling, as one may see any mass of metal cool that is poured out from a smelting-furnace to-day, in solid crystalline masses, without any division into separate layers or leaves; and the latter in successive beds, one over another, the heavier materials below, the lighter above, or sometimes in alternate layers, as special causes may have determined successive deposits of lighter or heavier materials at some given spot.

There were many well-fought battles between geologists before it was understood that these two elements had been equally active in building up the crust of the earth. The ground was hotly contested by the disciples of the two geological schools, one of which held that the solid envelope of the earth was exclusively due to the influence of fire, while the other insisted that it had been accumulated wholly under the agency of water. This difference of opinion grew up very naturally; for the great leaders of the two schools lived in different localities, and pursued their investigations over regions where the geological phenomena were of an entirely opposite character—the one exhibiting the effect of volcanic eruptions, the other that of stratified deposits. It was the old story of the two knights on opposite sides of the shield, one swearing that it was made of gold, the other that it was made of silver, and almost killing each other before they discovered that it was made of both. So prone are men to hug their theories and shut their eyes to any antagonistic facts, that it is related of Werner, the great leader of the Aqueous school, that he was actually on his way to see a geological locality of especial interest, but, being told that it confirmed the views of his opponents, he turned round and went home again, refusing to see what might force him to change his opinions. If the rocks did not confirm his theory, so much the worse for the rocks—he would

none of them. At last it was found that the two great chemists, fire and water, had worked together in the vast laboratory of the globe, and since then scientific men have decided to work together also; and if they still have a passage at arms occasionally over some doubtful point, yet the results of their investigations are ever drawing them nearer to each other—since men who study truth, when they reach their goal, must always meet at last on common ground.

The rocks formed under the influence of heat are called, in geological language, the Igneous, or, as some naturalists have named them, the Plutonic rocks, alluding to their fiery origin, while the others have been called Aqueous or Neptunic rocks, in reference to their origin under the agency of water. A simpler term, however, quite as distinctive, and more descriptive of their structure, is that of the stratified and massive or unstratified rocks. We shall see hereafter how the relative position of these two classes of rocks and their action upon each other enable us to determine the chronology of the earth, to compare the age of her mountains, and, if we have no standard by which to estimate the positive duration of her continents, to say at least which was the first-born among them, and how their characteristic features have been successfully worked out. I am aware that many of these inferences, drawn from what is called "the geological record," must seem to be the work of the imagination. In a certain sense this is true—for imagination, chastened by correct observation, is our best guide in the study of Nature. We are too apt to associate the exercise of this faculty with works of fiction, while it is in fact the keenest detective of truth.

Besides the stratified and massive rocks, there is still a third set, produced by the contact of these two, and called, in consequence of the changes thus brought about, the Metamorphic rocks. The effect of heat upon clay is to bake it into slate; limestone under the influence of heat becomes quicklime, or, if subjected afterward to the action of water, it is changed to mortar; sand under the same agency is changed to a coarse kind of glass. Suppose, then, that a volcanic eruption takes place in a region of the earth's surface where successive layers

of limestone, of clay, and of sandstone have been previously deposited by the action of water. If such an eruption has force enough to break through these beds, the hot, melted masses will pour out through the rent, flow over its edges, and fill all the lesser cracks and fissures produced by such a disturbance. What will be the effect upon the stratified rocks? Wherever these liquid masses, melted by a heat more intense than can be produced by any artificial means, have flowed over them or cooled in immediate contact with them, the clays will be changed to slate, the limestone will have assumed a character more like marble, while the sandstone will be vitrified. This is exactly what has been found to be the case, wherever the stratified rocks have been penetrated by the melted masses from beneath. They have been themselves partially melted by the contact, and when they have cooled again, their stratification, though still perceptible, has been partly obliterated, and their substance changed. Such effects may often be traced in dikes, which are only the cracks in rocks filled by materials poured into them at some period of eruption when the melted masses within the earth were thrown out and flowed like water into any inequality or depression of the surface around. The walls enclosing such a dike are often found to be completely altered by contact with its burning contents, and to have assumed a character quite different from the rocks of which they make a part; while the mass itself which fills the fissure shows by the character of its crystallization that it has cooled more quickly on the outside, where it meets the walls, than at the center.

The first two great classes of rocks, the unstratified and stratified rocks, represent different epochs in the world's physical history: the former mark its revolutions, while the latter chronicle its periods of rest. All mountains and mountain-chains have been upheaved by great convulsions of the globe, which rent asunder the surface of the earth, destroyed the animals and plants living upon it at the time, and were then succeeded by long intervals of repose, when all things returned to their accustomed order, ocean and river deposited fresh beds in uninterrupted succession, the accumulation of materials went

on as before, a new set of animals and plants were introduced, and a time of building up and renewing followed the time of destruction. These periods of revolution are naturally more difficult to decipher than the periods of rest; for they have so torn and shattered the beds they uplifted, disturbing them from their natural relations to each other, that it is not easy to reconstruct the parts and give them coherence and completeness again. But within the last half-century this work has been accomplished in many parts of the world with an amazing degree of accuracy, considering the disconnected character of the phenomena to be studied; and I think I shall be able to convince my readers that the modern results of geological investigation are perfectly sound logical inferences from well-established facts. In this, as in so many other things, we are but "children of a larger growth." The world is the geologist's great puzzle-box; he stands before it like the child to whom the separate pieces of his puzzle remain a mystery till he detects their relation and sees where they fit, and then his fragments grow at once into a connected picture beneath his hand. . . .

When geologists first turned their attention to the physical history of the earth, they saw at once certain great features which they took to be the skeleton and basis of the whole structure. They saw the great masses of granite forming the mountains and mountain-chains, with the stratified rocks resting against their slopes; and they assumed that granite was the first primary agent, and that all stratified rocks must be of a later formation. Although this involved a partial error, as we shall see hereafter when we trace the upheavals of granite even into comparatively modern periods, yet it held an important geological truth also; for, though granite formations are by no means limited to those early periods, they are nevertheless very characteristic of them, and are indeed the foundation-stones on which the physical history of the globe is built.

Starting from this landmark, the earlier geologists divided the world's history into three periods. As the historian recognizes Ancient History, the Middle Ages, and Modern History, as distinct phases in the growth of the human race, so they distinguished between what they called the Primary period, when,

as they believed, no life stirred on the surface of the earth; the Secondary or Middle period, when animals and plants were introduced, and the land began to assume continental proportions; and the Tertiary period, or comparatively modern geological times, when the physical features of the earth as well as its inhabitants were approaching more nearly to the present condition of things. But as their investigations proceeded, they found that every one of these great ages of the world's history was divided into numerous lesser epochs, each of which had been characterized by a peculiar set of animals and plants, and had been closed by some great physical convulsion, disturbing and displacing the materials accumulated during such a period of rest.

The further study of these subordinate periods showed that what had been called Primary formations, namely, the volcanic or Plutonic rocks formerly believed to be confined to the first geological ages, belonged to all the periods, successive eruptions having taken place at all times, pouring up through the accumulated deposits penetrating and injecting their cracks, fissures, and inequalities, as well as throwing out large masses on the surface. Up to our own day there has never been a period when such eruptions have not taken place, though they have been constantly diminishing in frequency and extent. In consequence of this discovery, that rocks of igneous character were by no means exclusively characteristic of the earliest times, they are now classified together upon very different grounds from those on which geologists first united them; though, as the name *Primary* was long retained, we still find it applied to them, even in geological works of quite recent date. This defect of nomenclature is to be regretted, as likely to mislead the student, because it seems to refer to time; whereas it no longer signifies the age of the rocks, but simply their character. The name Plutonic or Massive rocks is, however, now almost universally substituted for that of Primary.

A wide field of investigation still remains to be explored by the chemist and the geologist together, in the mineralogical character of the Plutonic rocks, which differs greatly in the different periods. The earlier eruptions seem to have been

chiefly granitic, though this must not be understood in too wide a sense since there are granite formations even as late as the Tertiary period; those of the middle periods were mostly porphyries and basalts; while in the more recent ones lavas predominate. We have as yet no clew to the laws by which this distribution of volcanic elements in the formation of the earth is regulated; but there is found to be a difference in the crystals of the Plutonic rocks belonging to different ages, which, when fully understood, may enable us to determine the age of any Plutonic rock by its mode of crystallization; so that the mineralogist will as readily tell you by its crystals whether a bit of stone of igneous origin belongs to this or that period of the world's history, as the palæontologist will tell you by its fossils whether a piece of rock of aqueous origin belongs to the Silurian or Devonian or Carboniferous deposits.

GEOLOGY

Composition and Material of the Earth's Crust

By AGNES GIBERNE

WHAT is the earth made of—this round earth upon which we human beings live and move?

A question more easily asked than answered, as regards a very large portion of it. For the earth is a huge ball nearly eight thousand miles in diameter, and we who dwell on the outside have no means of getting down more than a very little way below the surface. So it is quite impossible for us to speak positively as to the inside of the earth, and what it is made of. Some people believe the earth's inside to be hard and solid, while others believe it to be one enormous lake or furnace of fiery melted rock. But nobody really knows.

This outside crust has been reckoned to be of many different thicknesses. One man will say it is ten miles thick, and another will rate it at four hundred miles. So far as regards man's knowledge of it, gained from mining, from boring, from examination of rocks, and from reasoning out all that may be learned from these observations, we shall allow an ample margin if we count the field of geology to extend some twenty miles downwards from the highest mountain-tops. Beyond this we find ourselves in a land of darkness and conjecture.

Twenty miles is only one four-hundredth part of the earth's diameter—a mere thin shell over a massive globe. If the earth were brought down in size to an ordinary large school globe, a piece of rough brown paper covering it might well represent

the thickness of this earth-crust, with which the science of geology has to do. And the whole of the globe, this earth of ours, is but one tiny planet in the great Solar System. And the center of that Solar System, the blazing sun, though equal in size to more than a million earths, is yet himself but one star amid millions of twinkling stars, scattered broadcast through the universe. So it would seem at first sight that the field of geology is a small field compared with that of astronomy. . . . .

With regard to the great bulk of the globe little can be said. Very probably it is formed through and through of the same materials as the crust. This we do not know. Neither can we tell, even if it be so formed, whether the said materials are solid and cold like the outside crust, or whether they are liquid with heat. The belief has been long and widely held that the whole inside of the earth is one vast lake or furnace of melted fiery-hot material, with only a thin cooled crust covering it. Some in the present day are inclined to question this, and hold rather that the earth is solid and cold throughout, though with large lakes of liquid fire here and there, under or in the crust, from which our volcanoes are fed. . . .

The materials of which the crust is made are many and various; yet, generally speaking, they may all be classed under one simple word, and that word is—*Rock.*

It must be understood that, when we talk of rock in this geological sense, we do not only mean hard and solid stone, as in common conversation. Rock may be changed by heat into a liquid or "molten" state, as ice is changed by heat to water. Liquid rock may be changed by yet greater heat to vapor, as water is changed to steam, only we have in a common way no such heat at command as would be needed to effect this. Rock may be hard or soft. Rock may be chalky, clayey, or sandy. Rock may be so close-grained that strong force is needed to break it; or it may be so porous—so full of tiny holes—that water will drain through it; or it may be crushed and crumbled into loose grains, among which you can pass your fingers.

The cliffs above our beaches are rock; the sand upon our seashore is rock; the clay used in brick-making is rock; the

limestone of the quarry is rock; the marble of which our mantel-pieces are made is rock. The soft sandstone of South Devon, and the hard granite of the north of Scotland, are alike rock. The pebbles in the road are rock; the very mold in our gardens is largely composed of crumbled rock. So the word in its geological sense is a word of wide meaning.

Now the business of the geologist is to read the history of the past in these rocks of which the earth's crust is made.

Rocks may be divided into several kinds or classes. For the present moment it will be enough to consider the two grand divisions—*Stratified Rocks and Unstratified Rocks.*

Unstratified rocks are those which were once, at a time more or less distant, in a melted state from intense heat, and which have since cooled into a half *crystallized* state; much the same as water, when growing colder, cools and crystallizes into ice. Strictly speaking ice is rock, just as much as granite and sandstone are rock. Water itself is of the nature of rock, only as we commonly know it in the liquid state we do not commonly call it so.

"Crystallization" means those particular forms or shapes in which the particles of a liquid arrange themselves, as that liquid hardens into a solid—in other words, as it freezes. Granite, iron, marble, are frozen substances, just as truly as ice is a frozen substance; for with greater heat they would all become liquid like water. When a liquid freezes, there are always crystals formed, though these are not always visible without the help of a microscope. Also the crystals are of different shapes with different substances.

If you examine the surface of a puddle or pond, when a thin covering of ice is beginning to form, you will be able to see plainly the delicate, sharp, needle-like forms of the ice crystals. Break a piece of ice, and you will find that it will not easily break just in any way that you may choose, but it will only split along the lines of these needle-like crystals. This particular mode of splitting in a crystallized rock is called the *cleavage* of that rock.

Crystallization may take place either slowly or rapidly, and either in the open air or far below ground. The lava from a

volcano is an example of rock which has crystallized rapidly in the open air; and granite is an example of rock which has crystallized slowly underground beneath great pressure.

Stratified rocks, on the contrary, which make up a very large part of the earth's crust, are not crystallized. Instead of having cooled from a liquid into a solid state, they have been slowly *built up*, bit by bit and grain upon grain, into their present form, through long ages of the world's history. The materials of which they are made were probably once, long, long ago, the crumblings from granite and other crystallized rocks, but they show now no signs of crystallization.

They are called "stratified" because they are in themselves made up of distinct layers, and also because they lie thus one upon another in layers, or *strata*, just as the leaves of a book lie, or as the bricks of a house are placed.

Throughout the greater part of Europe, of Asia, of Africa, of North and South America, of Australia, these rocks are to be found, stretching over hundreds of miles together, north, south, east, and west, extending up to the tops of some of the earth's highest mountains, reaching down deep into the earth's crust. In many parts if you could dig straight downward through the earth for thousands of feet, you would come to layer after layer of these stratified rocks, one kind below another, some layers thick, some layers thin, here a stratum of gravel, there a stratum of sandstone, here a stratum of coal, there a stratum of clay.

But how, when, where, did the building up of all these rock-layers take place?

People are rather apt to think of land and water on the earth as if they were fixed in one changeless form—as if every continent and every island were of exactly the same shape and size now that it always has been and always will be.

Yet nothing can be further from the truth. The earth-crust is a scene of perpetual change, of perpetual struggle, of perpetual building up, of perpetual wearing away.

The work may go on slowly, but it does go on. The sea is always fighting against the land, beating down her cliffs, eating into her shores, swallowing bit by bit of solid earth; and rain

and frost and inland streams are always busily at work, helping the ocean in her work of destruction. Year by year and century by century it continues. Not a country in the world which is bordered by the open sea has precisely the same coastline that it had one hundred years ago; not a land in the world but parts each century with masses of its material, washed piecemeal away into the ocean.

See the effect upon the beach of one night's fierce storm. Mark the pathway on the cliff, how it seems to have crept so near the edge that here and there it is scarcely safe to tread; and very soon, as we know, it will become impassable. Just from a mere accident, of course—the breaking away of some of the earth, loosened by rain and frost and wind. But this is an accident which happens daily in hundreds of places around the shores.

Leaving the ocean, look now at this river in our neighborhood, and see the slight muddiness which seems to color its waters. What from? Only a little earth and sand carried off from the banks as it flowed—very unimportant and small in quantity, doubtless, just at this moment and just at this spot. But what of that little going on week after week, and century after century, throughout the whole course of the river, and throughout the whole course of every river and rivulet in our whole country and in every other country? A vast amount of material must every year be thus torn from the land and given to the ocean. For the land's loss here is the ocean's gain.

And, strange to say, we shall find that this same ocean, so busily engaged with the help of its tributary rivers in pulling down land, is no less busily engaged with their help in building it up.

You have sometimes seen directions upon a vial of medicine to "shake" before taking the dose. When you have so shaken the bottle the clear liquid grows thick; and if you let it stand for a while the thickness goes off, and a fine grain-like or dust-like substance settles down at the bottom—the settlement or *sediment* of the medicine. The finer this sediment, the slower it is in settling. If you were to keep the liquid in gentle motion the fine sediment would not settle down at the bottom.

With coarser and heavier grains the motion would have to be quicker to keep them supported in the water.

Now it is just the same thing with our rivers and streams. Running water can support and carry along sand and earth, which in still water would quickly sink to the bottom; and the more rapid the movement of the water, the greater is the weight it is able to bear.

This is plainly to be seen in the case of a mountain torrent. As it foams fiercely through its rocky bed it bears along, not only mud and sand and gravel, but stones and even small rocks, grinding the latter roughly together till they are gradually worn away, first to rounded pebbles, then to sand, and finally to mud. The material thus swept away by a stream, ground fine, and carried out to sea—part being dropped by the way on the river-bed—is called *detritus*, which simply means *worn-out* material.

The tremendous carrying-power of a mountain torrent can scarcely be realized by those who have not observed it for themselves. I have seen a little mountain-stream swell in the course of a heavy thunder-storm to such a torrent, brown and turbid with earth torn from the mountain-side, and sweeping resistlessly along in its career a shower of stones and rock-fragments. That which happens thus occasionally with many streams is more or less the work all the year round of many more.

As the torrent grows less rapid, lower down in its course, it ceases to carry rocks and stones, though the grinding and wearing away of stones upon the rocky bed continue, and coarse gravel is borne still upon its waters. Presently the widening stream, flowing yet more calmly, drops upon its bed all such coarser gravel as is not worn away to fine earth, but still bears on the lighter grains of sand. Next the slackening speed makes even the sand too heavy a weight, and that in turn falls to line the river-bed, while the now broad and placid stream carries only the finer particles of mud suspended in its waters. Soon it reaches the ocean, and the flow being there checked by the incoming ocean-tide, even the mud can no longer be held up, and it also sinks slowly in the shallows near the shore, forming sometimes broad mud-banks dangerous to the mariner.

This is the case only with smaller rivers. Where the stream is stronger, the mud-banks are often formed much farther out at sea; and more often still the river-detritus is carried away and shed over the ocean-bed, beyond the reach of our ken. The powerful rush of water in earth's greater streams bears enormous masses of sand and mud each year far out into the ocean, there dropping quietly the gravel, sand, and earth, layer upon layer at the bottom of the sea. Thus pulling down and building up go on ever side by side; and while land is the theater oftentimes of decay and loss, ocean is the theater oftentimes of renewal and gain.

Did you notice the word "sediment" used a few pages back about the settlement at the bottom of a medicine-vial?

There is a second name given to the stratified rocks, of which the earth's crust is so largely made up. They are called also *Sedimentary Rocks*.

The reason is simply this. The stratified rocks of the present day were once upon a time made up out of the sediment stolen first from land and then allowed to settle down on the sea-bottom.

Long, long ago, the rivers, the streams, the ocean, were at work, as they are now, carrying away rock and gravel, sand and earth. Then, as now, all this material, borne upon the rivers, washed to and fro by the ocean, settled down at the mouths of rivers or at the bottom of the sea, into a sediment, one layer forming up over another, gradually built up through long ages. At first it was only a soft, loose, sandy or muddy sediment, such as you may see on the seashore, or in a mud-bank. But as the thickness of the sediment increased, the weight of the layers above gradually pressed the lower layers into firm hard rocks; and still, as the work of building went on, these layers were, in their turn, made solid by the increasing weight over them. Certain chemical changes had also a share in the transformation from soft mud to hard rock, which need not be here considered.

All this has through thousands of years been going on. The land is perpetually crumbling away and fresh land under

the sea is being perpetually built up, from the very same materials which the sea and the rivers have so mercilessly stolen from continents and islands. This is the way, if geologists rightly judge, in which a very large part of the enormous formations of stratified or sedimentary rocks have been made.

So far is clear. But now we come to a difficulty.

The stratified rocks, of which a very large part of the continents is made, appear to have been built up slowly, layer upon layer, out of the gravel, sand, and mud, washed away from the land and dropped on the shore of the ocean.

You may see these layers for yourself as you walk out into the country. Look at the first piece of bluff rock you come near, and observe the clear pencil-like markings of layer above layer—not often indeed lying *flat*, one over another, and this must be explained later, but, however irregularly slanting, still plainly visible. You can examine these lines of stratification on the nearest cliff, the nearest quarry, the nearest bare headland, in your neighborhood.

But how can this be? If all these stratified rocks are built on the floor of the ocean out of material taken *from* the land, how can we by any possibility find such rocks *upon* the land? In the beds of rivers we might indeed expect to see them, but surely nowhere else save under ocean waters.

Yet find them we do. Through the two great world-continents, they abound on every side. Thousands of miles in unbroken succession are composed of such rocks.

Stand with me near the seashore, and let us look around. See, in the rough sides of yonder bluff the markings spoken of, fine lines running alongside of one another, sometimes flat, sometimes bent or slanting, but always giving the impression of layer piled upon layer. Yet how can one for a moment suppose that the ocean-waters ever rose so high? Look again at yonder cliff, and observe a little way below the top a singular band of shingles, squeezed into the cliff, as it were, with chalk below and earth above.

That is believed to be an old sea-beach. Once upon a time the waters of the sea are supposed to have washed those shin-

gles, as now they wash the shore near which we stand, and all the white cliff must have lain then beneath the ocean.

Geologists were for a long while sorely puzzled to account for these old sea-beaches, found high up in the cliffs around our land in many different places.

They had at first a theory that the sea must once, in far back ages, have been a great deal higher than it is now. But this explanation only brought about fresh difficulties. It is quite impossible that the level of the sea should be higher in one part of the world than in another. Besides, in some places remains of sea-animals are found in mountain heights, as much as two or three thousand feet above the sea-level—as, for instance, in Corsica. This very much increases the difficulty of the above explanation.

So another theory was started instead, and this is now generally supposed to be the true one. What if, instead of the whole ocean having been higher, parts of the land were lower? England at one time, parts of Europe at another time, parts of Asia and America at other times, may have slowly sunk beneath the ocean, and after long remaining there have slowly risen again.

This is by no means so wild a supposition as it may seem when first heard, and as it doubtless did seem when first proposed. For even in the present day these movements of the solid crust of our earth are going on. The coasts of Sweden and Finland have long been slowly and steadily rising out of the sea, so that the waves can no longer reach so high upon those shores as in years gone by they used to reach. In Greenland, on the contrary, land has long been slowly and steadily sinking, so that what used to be the shore now lies under the sea. Other such risings and sinkings might be mentioned, as also many more in connection with volcanoes and earthquakes, which are neither slow nor steady, but sudden and violent.

So it becomes no impossible matter to believe that, in the course of ages past, all those wide reaches of our continents and islands, where sedimentary rocks are to be found, were each in turn, at one time or another, during long periods, beneath the rolling waters of the ocean. . . .

These built-up rocks are not only called "Stratified," and "Sedimentary." They have also the name of *Aqueous Rock*, from the Latin word *aqua*, *water;* because they are believed to have been formed by the action of the water.

They have yet another and fourth title, which is *Fossiliferous Rocks*.

Fossils are the hardened remains of animals and vegetables found in rocks. They are rarely, if ever, seen in unstratified rocks; but many layers of stratified rocks abound in these remains. Whole skeletons as well as single bones, whole tree-trunks as well as single leaves, are found thus embedded in rock layers, where in ages past the animal or plant died and found a grave. They exist by thousands in many parts of the world, varying in size from the huge skeleton of the elephant to the tiny shell of the microscopic animalcule.

Fossils differ greatly in kind. Sometimes the entire shell or bone is changed into stone, losing all its animal substance, but retaining its old outline and its natural markings. Sometimes the fossil is merely the hardened impress of the outside of a shell or leaf, which has dented its picture on soft clay, and has itself disappeared, while the soft clay has become rock, and the indented picture remains fixed through after-centuries. Sometimes the fossil is the cast of the inside of a shell; the said shell having been filled with soft mud, which has taken its exact shape and hardened, while the shell itself has vanished. The most complete description of fossil is the first of these three kinds. It is wonderfully shown sometimes in fossil wood, where all the tiny cells and delicate fibers remain distinctly marked as of old, only the whole woody substance has changed into hard stone.

But although the fossil remains of quadrupeds and other land-animals are found in large quantities, their number is small compared with the enormous number of fossil sea-shells and sea-animals.

Land-animals, as a rule, have been so preserved only when they have been drowned in ponds or rivers, or mired in bogs and swamps, or overtaken by frost or swept out to sea.

Sea-animals, on the contrary, have been so preserved on

land whenever that land has been under the sea; and this appears to have been the case, at one or another past age, with the greater part of our present continents. These fossil remains of sea animals are discovered in all quarters of the world, not only on the seashore but also far inland, not only deep down underground but also high up on the tops of lofty mountains —a plain proof that over the summits of those mountains the ocean must once have rolled, and this not for a brief space only, but through long periods of time. And not on the mountain-summit only are these fossils known to abound, but sometimes in layer below layer of the mountain, from top to bottom, through thousands of feet of rock.

This may well seem puzzling at first sight. Fossils of sea-creatures on a mountain-top are startling enough; yet hardly so startling as the thought of fossils *inside* that mountain. How could they have found their way thither?

The difficulty soon vanishes, if once we clearly understand that all these thousands of feet of rock were built up slowly, layer after layer, when portions of the land lay deep under the sea. Thus *each separate layer* of mud or sand or other material became in its turn the *top layer*, and was for the time the floor of the ocean, until further droppings of material out of the waters made a fresh layer, covering up the one below.

While each layer was thus in succession the top layer of the building, and at the same time the floor of the ocean, animals lived and died in the ocean, and their remains sank to the bottom, resting upon the sediment floor. Thousands of such dead remains disappeared, crumbling into fine dust and mingling with the waters, but here and there one was caught captive by the half-liquid mud, and was quickly covered and preserved from decay. And still the building went on, and still layer after layer was placed, till many fossils lay deep down beneath the later-formed layers; and when at length, by slow or quick upheaval of the ground, this sea-bottom became a mountain, the little fossils were buried within the body of that mountain. So wondrously the matter appears to have come about.

Another difficulty with respect to the stratified rocks has to be thought of. All these layers or deposits of gravel, sand, or

earth, on the floor of the ocean, would naturally be horizontal —that is, would lie flat, one upon another. In places the ocean-floor might slant, or a crevice or valley or ridge might break the smoothness of the deposit. But though the layers might partake of the slant, though the valley might have to be filled, though the ridge might have to be surmounted, still the general tendency of the waves would be to level the dropping deposits into flat layers.

Then how is it that when we examine the strata of rocks in our neighborhood, wherever that neighborhood may be, we do not find them so arranged? Here, it is true, the lines for a space are nearly horizontal, but there, a little way farther on, they are perpendicular; here they are bent, and there curved; here they are slanting, and there crushed and broken.

This only bears out what has been already said about the Book of Geology. It *has* been bent and disturbed, crushed and broken.

Great powers have been at work in this crust of our earth. Continents have been raised, mountains have been upheaved, vast masses of rock have been scattered into fragments. Here or there we may find the layers arranged as they were first laid down, but far more often we discover signs of later disturbance, either slow or sudden, varying from a mere quiet tilting to a violent overturn.

So the Book of Geology is a torn and disorganized volume, not easy to read.

Yet, on the other hand, these very changes which have taken place are a help to the geologist.

It may seem at first sight as if we should have an easier task, if the strata were all left lying just as they were first formed, in smooth level layers, one above another. But if it were so, we could know very little about the lower layers.

We might indeed feel sure, as we do now, that the lowest layers were the oldest and the top layers the newest, and that any fossils found in the lower layers must belong to an age farther back than any fossils found in the upper layers.

So much would be clear. And we might dig also and burrow a little way down, through a few different kinds of rock,

16

where they were not too thick. But that would be all. There our powers would cease.

Now how different. Through the heavings and tiltings of the earth's crust, the lower layers are often pushed quite up to the surface, so that we are able to examine them and their fossils without the least difficulty, and very often without digging underground at all.

You must not suppose that the real order of the rocks is changed by these movements, for generally speaking it is not. The lower kinds are rarely, if ever, found placed *over* the upper kinds; only the ends of them are seen peeping out above ground.

It is as if you had a pile of copy-books lying flat one upon another, and were to put your finger under the lowest and push it up. All those above would be pushed up also, and perhaps they would slip a little way down, so that you would have a row of *edges* showing side by side, at very much the same height. The arrangement of the copy-books would not be changed, for the lowest would still be the lowest in actual position; but a general tilting or upheaval would have taken place.

Just such a tilting or upheaval has taken place again and again with the rocks forming our earth-crust. The edges of the lower rocks often show side by side with those of higher layers.

But geologists know them apart. They are able to tell confidently whether such and such a rock, peeping out at the earth's surface, belongs really to a lower or a higher kind. For there is a certain sort of order followed in the arrangement of rock-layers all over the earth, and it is well known that some rocks are never found below some other rocks, that certain particular kinds are never placed above certain other kinds. Thus it follows that the fossils found in one description of rock must be the fossils of animals which lived and died before the animals whose fossil remains are found in another neighboring rock, just because this last rock-layer was built upon the ocean-floor above and therefore later than the other.

All this is part of the foreign language of geology—part of the piecing and arranging of the torn volume. Many mistakes

are made; many blunders are possible; but the mistakes and blunders are being gradually corrected, and certain rules by which to read and understand are becoming more and more clear.

It has been already said that unstratified rocks are those which have been at some period, whether lately or very long ago, in a liquid state from intense heat, and which have since cooled, either quickly or slowly, crystallizing as they cooled.

Unstratified rocks may be divided into two distinct classes.

First.—Volcanic rocks, such as lava. These have been quickly cooled at the surface of the earth, or not far below it.

Secondly.—Plutonic rocks, such as granite. These have been slowly cooled deep down in the earth under heavy pressure.

There is also a class of rocks, called metamorphic rocks, including some kinds of marble. These are, strictly speaking, crystalline rocks, and yet they are arranged in something like layers. The word "metamorphic" simply means "transformed." They are believed to have been once stratified rocks, perhaps containing often the remains of animals; but intense heat has later transformed them into crystalline rocks, and the animal remains have almost or quite vanished.

Just as the different kinds of stratified rocks are often called aqueous rocks, or rocks formed by the action of water—so these different kinds of unstratified rocks are often called igneous rocks, or rocks formed by the action of fire—the name being taken from the Latin word for fire. The metamorphic rocks are sometimes described as "Aqueo-igneous," since both water and fire helped in the forming of them.

It was at one time believed, as a matter of certainty, that granite and such rocks belonged to a period much farther back than the periods of the stratified rocks. That is to say, it was supposed that fire-action had come first and water-action second; that the fire-made rocks were all formed in very early ages, and that only water-made rocks still continued to be formed. So the name of Primary Rocks, or First Rocks, was given to the granites and other such rocks, and the name of Secondary Rocks to all water-built rocks, while those of the third class were called Transition Rocks, because they seemed

to be a kind of link or stepping-stone in the change from the First to the Second Rocks.

The chief reason for the general belief that fire-built rocks were older than water-built ones was, that the former are as a rule found to lie *lower* than the latter. They form, as it were, the basement of the building, while the top-stories are made of water-built rocks.

Many still believe that there is much truth in the thought. It is most probable, so far as we are able to judge, that the *first formed* crust of rocks all over the earth was of cooled and crystallized material. As these rocks were crumbled and wasted by the ocean, materials would have been supplied for the building-up of rocks, layer upon layer.

But this is conjecture. We cannot know with any certainty the course of events so far back in the past. And geologists are now able to state with tolerable confidence that, however old many of the granites may be, yet a large amount of the fire-built rocks are no older than the water-built rocks which lie over them.

So by many geologists the names of Primary, Transition, and Secondary Formations are pretty well given up. It has been proposed to give instead to the crystallized rocks of all kinds the name of Underlying Rocks (Hypogene Rocks).

But if they really do lie under, how can they possibly be of the same age? One would scarcely venture to suppose, in looking at a building, that the cellars had not been finished before the upper floors.

True. In the first instance doubtless the cellars were first made, then the ground-floor, then the upper stories.

When, however, the house was so built, alterations and improvements might be very widely carried on above and below. While one set of workmen were engaged in remodeling the roof, another set of workmen might be engaged in remodeling the kitchens and first floor, pulling down, propping up, and actually rebuilding parts of the lower walls.

This is precisely what the two great fellow-workmen, Fire and Water, are ever doing in the crust of our earth. And if it be objected that such alterations too widely undertaken might

result in slips, cracks, and slidings, of ceilings and walls in the upper stories, I can only say that such catastrophes *have* been the result of underground alterations in that great building, the earth's crust. . . .

We see therefore clearly that, although the earliest fire-made rocks may very likely date farther back than the earliest water-made rocks, yet the making of the two kinds has gone on side by side, one below and the other above ground, through all ages up to the present moment.

And just as in the present day water continues its busy work above ground of pulling down and building up, so also fire continues its busy work underground of melting rocks which afterward cool into new forms, and also of shattering and upheaving parts of the earth-crust.

For there can be no doubt that fiery heat does exist as a mighty power within our earth, though to what extent we are not able to say.

These two fellow-workers in nature have different modes of working. One we can see on all sides, quietly progressing, demolishing land patiently bit by bit, building up land steadily grain by grain. The other, though more commonly hidden from sight, is fierce and tumultuous in character, and shows his power in occasional terrific outbursts.

We can scarcely realize what the power is of the imprisoned fiery forces underground, though even we are not without some witness of their existence. From time to time even our firm land has been felt to tremble with a thrill from some far-off shock; and even in our country is seen the marvel of scalding water pouring unceasingly from deep underground . . . .

Think of the tremendous eruptions of Vesuvius, of Etna, of Hecla, of Mauna Loa. Think of whole towns crushed and buried, with their thousands of living inhabitants. Think of rivers of glowing lava streaming up from regions below ground, and pouring along the surface for a distance of forty, fifty, and even sixty miles, as in Iceland and Hawaii. Think of red-hot cinders flung from a volcano-crater to a height of 10,000 feet. Think of lakes of liquid fire in other craters, five hundred to a

thousand feet across, huge caldrons of boiling rock. Think of showers of ashes from the furnace below of yet another, borne so high aloft as to be carried seven hundred miles before they sank to earth again. Think of millions of red-hot stones flung out in one eruption of Vesuvius. Think of a mass of rock, one hundred cubic yards in size, hurled to a distance of eight miles or more out of the crater of Cotopaxi.

Think also of earthquake-shocks felt through 1,200 miles of country. Think of fierce tremblings and heavings lasting in constant succession through days and weeks of terror. Think of hundreds of miles of land raised several feet in one great upheaval. Think of the earth opening in scores of wide-lipped cracks, to swallow men and beasts. Think of hot mud, boiling water, scalding steam, liquid rock, bursting from such cracks, or pouring from rents in a mountain-side.

Truly these are signs of a state of things in or below the solid crust on which we live, that may make us doubt the absolute security of "Mother Earth."

Different explanations have been put forward to explain this seemingly fiery state of things underground.

Until lately the belief was widely held that our earth was one huge globe of liquid fire, with only a slender cooled crust covering her, a few miles in thickness.

This view was supported by the fact that heat is found to increase as men descend into the earth. Measurements of such heat-increase have been taken, both in mines and in borings for wells. The usual rate is about one degree more of heat, of our common thermometer, for every fifty or sixty feet of descent. If this were steadily continued, water would boil at a depth of 8,000 feet below the surface; iron would melt at a depth of twenty-eight miles; while at a depth of forty or fifty miles no known substance upon earth could remain solid.

The force of this proof is, however, weakened by the fact that the rate at which the heat increases differs very much in different places. Also it is now generally supposed that such a tremendous furnace of heat—a furnace nearly 8,000 miles in

diameter—could not fail to break up and melt so slight a covering shell.

Many believe, therefore, not that the whole interior of the earth is liquid with heat, but that enormous fire-seas or lakes of melted rock exist here and there, under or in the earth-crust. From these lakes the volcanoes would be fed, and they would be the cause of earthquakes and land-upheavals or land-sinking. There are strong reasons for supposing that the earth was once a fiery liquid body, and that she has slowly cooled through long ages. Some hold that her center probably grew solid first from tremendous pressure; that her crust afterward became gradually cold; and that between the solid crust and the solid inside or "nucleus," a sea of melted rock long existed, the remains of which are still to be found in these tremendous fiery reservoirs.

The idea accords well with the fact that large numbers of extinct or dead volcanoes are scattered through many parts of the earth. If the above explanation be the right one, doubtless the fire-seas in the crust extended once upon a time beneath such volcanoes, but have since died out or smoldered low in those parts.

A somewhat curious calculation has been made, to illustrate the different modes of working of these two mighty powers—Fire and Water.

The amount of land swept away each year in mud, and borne to the ocean by the River Ganges, was roughly reckoned, and also the amount of land believed to have been upheaved several feet in the great Chilian earthquake.

It was found that the river, steadily working month by month, would require some four hundred years to carry to the sea the same weight of material, which in one tremendous effort was upheaved by the fiery underground forces.

Yet we must not carry this distinction too far. Fire does not always work suddenly, or water slowly; witness the slow rising and sinking of land in parts of the earth, continuing through centuries; and witness also the effects of great floods and storms.

The crust of the earth is made of rock. But what is rock made of?

Certain leading divisions of rocks have been already considered:

The Water-made Rocks;

The Fire-made Rocks, both Plutonic and Volcanic;

The Water-and-Fire-made Rocks.

The first of these—Water-made Rocks—may be subdivided into three classes. These are,—

I. *Flint Rocks;*

II. *Clay Rocks;*

III. *Lime Rocks.*

This is not a book in which it would be wise to go closely into the mineral nature of rocks. Two or three leading thoughts may, however, be given.

Does it not seem strange that the hard and solid rocks should be in great measure formed of the same substances which form the thin invisible air floating around us?

Yet so it is. There is a certain gas called oxygen gas. Without that gas you could not live many minutes. Banish it from the room in which you are sitting, and in a few minutes you will die.

This gas makes up nearly one-quarter by weight of the atmosphere round the whole earth.

The same gas plays an important part in the ocean; for more than three-quarters of water is *oxygen.*

It plays also an important part in rocks; for about half the material of the entire earth's crust is oxygen.

Another chief material in rocks is *silicon.* This makes up one-quarter of the crust, leaving only one-quarter to be accounted for. Silicon mixed with oxygen makes silica or quartz. There are few rocks which have not a large amount of quartz in them. Common flint, sandstones, and the sand of our shores are made of quartz, and therefore belong to the first class of silicious or flint rocks. Granites and lavas are about one-half quartz. The beautiful stones, amethyst, agate, chalcedony, and jasper, are all different kinds of quartz.

Another chief material in rocks is a white metal called *aluminium.* United to oxygen it becomes alumina, the chief substance in clay. Rocks of this kind—such as clays, and also

the lovely blue gem, sapphire—are called argillaceous rocks, from the Latin word for clay, and belong to the second class. Such rocks keep fossils well.

Another is *calcium*. United to oxygen and carbonic acid, it makes carbonate of lime, the chief substance in limestone; so all limestones belong to the third class of calcareous or lime rocks.

Other important materials may be mentioned, such as *magnesium*, *potassium*, *sodium*, *iron*, *carbon*, *sulphur*, *hydrogen*, *chlorine*, *nitrogen*. These, with many more, not so common, make up the remaining quarter of the earth-crust.

Carbon plays as important a part in animal and vegetable life as silicon in rocks. Carbon is most commonly seen in three distinct forms—as charcoal, as black-lead, and as the pure brilliant diamond. Carbon united, in a particular proportion, to oxygen, forms carbonic acid; and carbonic acid united, in a particular proportion, to lime, forms limestone.

Hydrogen united to oxygen forms water. Each of these two gases is invisible alone, but when they meet and mingle they form a liquid.

Nitrogen united to oxygen and to a small quantity of carbonic acid gas forms our atmosphere.

Rocks of pure flint, pure clay, or pure lime are rarely or never met with. Most rocks are made up of several different substances melted together.

In the fire-built rocks no remains of animals are found, though in water-built rocks they abound. Water-built rocks are sometimes divided into two classes—those which only contain occasional animal remains, and those which are more or less built up of the skeletons of animals.

There are some exceedingly tiny creatures inhabiting the ocean, called Rhizopods. They live in minute shells, the largest of which may be almost the size of a grain of wheat, but by far the greater number are invisible as shells without a microscope, and merely show as fine dust. The rhizopods are of different shapes, sometimes round, sometimes spiral, sometimes having only one cell, sometimes having several cells. In

the latter case a separate animal lives in each cell. The animal is of the very simplest as well as the smallest kind. He has not even a mouth or a stomach, but can take in food at any part of his body.

These rhizopods live in the oceans in enormous numbers. Tens of millions are ever coming into existence, living out their tiny lives, dying, and sinking to the bottom. There upon the ocean-floor gather their remains, a heaped-up multitude of minute skeletons or shells, layer forming over layer.

It was long suspected that the white chalk cliffs of England were built up in some such manner as this through past ages. And now at length proof has been found, in the shape of mud dredged up from the ocean-bottom—mud entirely composed of countless multitudes of these little shells, dropping there by myriads, and becoming slowly joined together in one mass.

Just so, it is believed, were the white chalk cliffs built—gradually prepared on the ocean-floor, and then slowly or suddenly upheaved, so as to become a part of the dry land.

Think what the enormous numbers must have been of tiny living creatures, out of whose shells the wide reaches of white chalk cliffs have been made. Chalk cliffs and chalk layers extend from Ireland, through England and France, as far as to the Crimea. In the south of Russia they are said to be six hundred feet thick. Yet one cubic inch of chalk is calculated to hold the remains of more than one million rhizopods. How many countless millions upon millions must have gone to the whole structure! How long must the work of building up have lasted!

These little shells do not always drop softly and evenly to the ocean-floor, to become quietly part of a mass of shells. Sometimes, where the ocean is shallow enough for the waves to have power below, or where land currents can reach, they are washed about, and thrown one against another, and ground into fine powder; and the fine powder becomes in time, through different causes, solid rock.

Limestone is made in another way also. In the warm waters of the South Pacific Ocean there are many islands,

large and small, which have been formed in a wonderful manner by tiny living workers. The workers are soft jelly-like creatures, called polyps, who labor together in building up great walls and masses of coral.

They never carry on their work above the surface of the water, for in the air they would die. But the waves break the coral, and heap it up above high-water mark, and carry earth and seeds to drop there till at length a small low-lying island is formed.

The waves not only heap up broken coral, but they grind the coral into fine powder, and from this powder limestone rock is made, just as it is from the powdered shells of rhizopods. The material used by the polyps in building the coral is chiefly lime, which they have the power of gathering out of the water, and the fine coral-powder, sinking to the bottom, makes large quantities of hard limestone. Soft chalk is rarely, if ever, found near the coral islands.

Limestones are formed in the same manner from the grinding up of other sea-shells and fossils, various in kind; the powder becoming gradually united into solid rock.

There is yet another way in which limestone is made, quite different from all these. Sometimes streams of water have a large quantity of lime in them; and these as they flow will drop layers of lime which harden into rock. Or a lime-laden spring, making its way through the roof of an underground cavern, will leave all kinds of fantastic arrangements of limestone wherever its waters can trickle and drip. Such a cavern is called a "stalactite cave."

So there are different kinds of fossil rock-making. There may be rocks made of other materials, with fossil simply buried in them. There may be rocks made entirely of fossils, which have gathered in masses as they sank to the sea-bottom, and have there become simply and lightly joined together. There may be rocks made of the ground-up powder of fossils, pressed into a solid substance or united by some other substance.

Rocks are also often formed of whole fossils, or stones, or shells, bound into one by some natural soft sticky cement,

which has gathered round them and afterward grown hard, like the cement which holds together the stones in a wall.

The tiny rhizopods (meaning root foot), which have so large a share in chalk and limestone making, are among the smallest and simplest known kinds of animal life.

There are also some very minute forms of vegetable life, which exist in equally vast numbers, called diatoms. For a long while they were believed to be living animals, like the rhizopods. Scientific men are now, however, pretty well agreed that they really are only vegetables or plants.

The diatoms have each one a tiny shell or shield, not made of lime like the rhizopod-shells, but of flint. Some think that common flint may be formed of these tiny shells.

Again, there is a kind of rock called mountain meal, which is entirely made up of the remains of diatoms. Examined under the microscope, thousands of minute flint shields of various shapes are seen. This rock, or earth, is very abundant in many places, and is sometimes used as a polishing powder. In Bohemia there is a layer of it no less than fourteen feet thick. Yet so minute are the shells of which it is composed, that one square inch of rock is said to contain about four thousand millions of them. Each one of these millions is a separate distinct fossil . . . .

If you examine carefully a piece of coal, you will find, more or less clearly, markings like those which are seen in a piece of wood. Sometimes they are very distinct indeed. Coal abounds in impressions of leaves, ferns, and stems, and fossil remains of plants and tree-trunks are found in numbers in coal-seams.

Coal is a vegetable substance. The wide coal-fields of Britain and other lands are the *fossil* remains of vast forests.

Long ages ago, as it seems, broad and luxuriant forests flourished over the earth. In many parts generation after generation of trees lived and died and decayed, leaving no trace of their existence, beyond a little layer of black mold, soon to be carried away by wind and water. Coal could only be formed where there were bogs and quagmires.

But in bogs and quagmires, and in shallow lakes of low-

lying lands, there were great gatherings of slowly decaying vegetable remains, trees, plants, and ferns all mingling together. Then after a while the low lands would sink and the ocean pouring in would cover them with layers of protecting sand or mud; and sometimes the land would rise again, and fresh forests would spring into life, only to be in their turn overwhelmed anew, and covered by fresh sandy or earthy deposits.

These buried forests lay through the ages following, slowly hardening into the black and shining coal, so useful now to man.

The coal is found thus in thin or thick seams, with other rock-layers between, telling each its history of centuries long past. In one place no less than sixteen such beds of coal are found, one below another, each divided from the next above and the next underneath by beds of clay or sand or shale. The forests could not have grown in the sea, and the earth-layers could not have been formed on land, therefore many land-risings and sinkings must have taken place. Each bed probably tells the tale of a succession of forests. . . . . .

Before going on to a sketch of the early ages of the Earth's history—ages stretching back long long before the time of Adam—it is needful to think yet for a little longer about the manner in which that history is written, and the way in which it has to be read.

For the record is one difficult to make out, and its style of expression is often dark and mysterious. There is scarcely any other volume in the great Book of Nature which the student is so likely to misread as this one. It is very needful, therefore, to hold the conclusions of geologists with a light grasp, guarding each with a "perhaps" or a "may be." Many an imposing edifice has been built, in geology, upon a rickety foundation which has speedily given way.

In all ages of the world's history up to the present day, rock-making has taken place—fire-made rocks being fashioned underground, and water-made rocks being fashioned above ground though under water.

Also in all ages different kinds of rocks have been fashioned

side by side—limestone in one part of the world, sandstone in another, chalk in another, clay in another, and so on. There have, it is true, been ages when one kind seems to have been the *chief* kind—an age of limestone, or an age of chalk. But even then there were doubtless more rock-buildings going on, though not to so great an extent. On the other hand, there may have been ages during which no limestone was made, or no chalk, or no clay. As a general rule, however, the various sorts of rock-building have probably gone on together. This was not so well understood by early geologists as it is now.

The difficulty is often great of disentangling the different strata, and saying which was earlier and which later formed.

Still, by close and careful study of the rocks which compose the earth's crust, a certain kind of order is found to exist, more or less followed out in all parts of the world. *When* each layer was formed in England or in America, the geologist cannot possibly say. He can, however, assert, in either place, that a certain mass of rock was formed before a certain other mass in that same place, even though the two may seem to lie side by side; for he knows that they were so placed only by upheaval, and that once upon a time the one lay beneath the other.

The geologist can go further. He can often declare that a certain mass of rock in America and a certain mass of rock in England, quite different in kind, were probably built up at about the same time. How long ago that time was he would be rash to attempt to say; but that the two belong to the same age he has good reason for supposing.

We find rocks piled upon rocks in a certain order, so that we may generally be pretty confident that the lower rocks were first made, and the upper rocks the latest built. Further than this, we find in all the said layers of water-built rocks signs of past life.

As already stated, much of this life was ocean-life, though not all.

Below the sea, as the rock-layers were being formed, bit by bit, of earth dropping from the ocean to the ocean's floor, sea-creatures lived out their lives and died by thousands, to sink to that same floor. Millions passed away, dissolving and leaving

no trace behind; but thousands were preserved—shells often, animals sometimes.

Nor was this all. For now and again some part of the sea-bottom was upheaved, slowly or quickly, till it became dry land. On this dry land animals lived again, and thousands of them, too, died, and their bones crumbled into dust. But here and there one was caught in bog or frost, and his remains were preserved till, through lapse of ages, they turned to stone.

Yet again that land would sink, and over it fresh layers were formed by the ocean-waters, with fresh remains of sea-animals buried in with the layers of sand or lime; and once more the sea-bottom would rise, perhaps then to continue as dry land, until the day when man should discover and handle these hidden remains.

Now note a remarkable fact as to these fossils, scattered far and wide through the layers of stratified rock. In the uppermost and latest-built rocks the animals found are the same, in great measure, as those which now exist upon the earth.

Leaving the uppermost rocks, and examining those which lie a little way below we find a difference. Some are still the same, and others, if not quite the same, are very much like what we have now; but here and there a creature of a different form appears.

Go deeper still, and the kinds of animals change further. Fewer and fewer resemble those which now range the earth; more and more belong to other species.

Descend through layer after layer till we come to rocks built in earliest ages, and not one fossil shall we find precisely the same as one animal living now.

So not only are the rocks built in successive order, stratum after stratum belonging to age after age in the past, but fossil-remains also are found in successive order, kind after kind belonging to past age after age.

Although in the first instance the succession of fossils was understood by means of the succession of rock-layers, yet in the second place the arrangement of rock-layers is made more clear by the means of these very fossils.

A geologist, looking at the rocks in America, can say which

there were first-formed, which second-formed, which third-formed. Also, looking at the rocks in England, he can say which there were first-formed, second-formed, third-formed. He would, however, find it very difficult, if not impossible, to say which among any of the American rocks was formed at about the same time as any particular one among the English rocks, were it not for the help afforded him by these fossils.

Just as the regular succession of rock-strata has been gradually learned, so the regular succession of different fossils is becoming more and more understood. It is now known that some kinds of fossils are always found in the oldest rocks, and in them only; that some kinds are always found in the newest rocks, and in them only; that some fossils are rarely or never found lower than certain layers; that some fossils are rarely or never found higher than certain other layers.

So this fossil arrangement is growing into quite a history of the past. And a geologist, looking at certain rocks, pushed up from underground, in England and in America, can say: "These are very different kinds of rocks, it is true, and it would be impossible to say how long the building up of the one might have taken place before or after the other. But I see that in both these rocks there are exactly the same kinds of fossil-remains, differing from those in the rocks above and below. I conclude therefore that the two rocks belong to about the same great age in the world's past history, when the same animals were living upon the earth."

Observing and reasoning thus, geologists have drawn up a general plan or order of strata; and the whole of the vast masses of water-built rocks throughout the world have been arranged in a regular succession of classes, rising step by step from earliest ages up to the present time.

PHYSICAL GEOGRAPHY

The Atmosphere

By ELISHA GRAY

METEOROLOGY is a science that at one time included astronomy, but now it is restricted to the weather, seasons, and all phenomena that are manifested in the atmosphere in its relation to heat, electricity, and moisture, as well as the laws that govern the ever-varying conditions of the circumambient air of our globe. The air is made up chiefly of oxygen and nitrogen, in the proportions of about twenty-one parts of oxygen and seventy-nine parts nitrogen by volume, and by weight about twenty-three parts of oxygen and seventy-seven of nitrogen. These gases exist in the air as free gases and not chemically combined. The air is simply a mixture of these two gases.

There is a difference between a mixture and a compound. In a mixture there is no chemical change in the molecules of the substances mixed. In a compound there has been a rearrangement of the atoms, new molecules are formed, and a new substance is the result.

About ninety-nine and one-half per cent. of air is oxygen and nitrogen, and one-half per cent is chiefly carbon dioxide. Carbon dioxide is a product of combustion, decay, and animal exhalation. It is poison to the animal, but food for the vegetable. The proportion in the air is so small however, that its baneful influence upon animal life is reduced to a minimum. The nitrogen is an inert, odorless gas, and its use in the air seems to be to dilute it, so that man and animals can breathe it. If all the nitrogen were extracted from the air and only

the oxygen left to breathe, all animal life would be stimulated to death in a short time. The presence of the nitrogen prevents too much oxygen from being taken into the system at once.

Air contains more or less moisture in the form of vapor; this subject, however, will be discussed more fully under the head of evaporation. The air at sea-level weighs fifteen pounds to the square inch, and if the whole envelope of air were homogeneous—the same in character—it would reach only about five miles high. But as it becomes gradually rarefied as we ascend it probably extends in a very thin state to a height of eighty or ninety miles; at least, at that heighτ we should find a more perfect vacuum than can be produced by artificial means. The weight of all the air on the globe would be eleven and two-thirds trillion pounds if no deduction had to be made for space filled by mountains and land above sea-level. As it is, the whole bulk weighs something less than the above figures.

The air envelopes the globe to a height at sea-level of eighty or ninety miles, gradually thinning out into the ether that fills all interstellar space. We live and move on the bottom of a great ocean of air. The birds fly in it just as the fish swim in the ocean of water. Both are transparent and both have weight. Water in the condensed state is heavier than the air and will seek the lowest places, but when vaporized, as in the process of evaporation, it is lighter than air and floats upward. In the vapor state it is transparent like steam. If you study a steam jet you will notice that for a short distance after it issues from the boiler it is transparent, but soon it condenses into cloud.

If we could see inside of a boiler in which steam had been generated, all the space not occupied with water would seem to be vacant, since steam, before it is condensed, is as transparent as the air. We will, however, speak of this subject more fully under the head of evaporation and cloud formation. It is not enough that we have the air in which we live and move, with all of its properties, as we have described: something more is needed which is absolutely essential both to animal and vegetable life—and this essential is motion. If the air remained

perfectly still with no lateral movement or upward and downward currents of any kind, we should have a perfectly constant condition of things subjected only to such gradual changes as the advancing and receding seasons would produce owing to the change in the angle of the sun's rays. No cloud would ever form, no rain would ever fall, and no wind would ever blow. It is of the highest importance not only that the wind shall blow, but that comparatively sudden changes of temperature take place in the atmosphere, in order that vegetation as well as animal life may exist upon the surface of the globe. The only place where animal life could exist would be in the great bodies of water, and it is even doubtful if water could remain habitable unless there were means provided for constant circulation—motion.

The mobility of the atmosphere is such that the least influence that changes its balance will put it in motion. While we can account in a general way for atmospheric movements, there are many problems relating to the details that are unsolved. We find that even the "weather man" makes mistakes in his prognostications; so true is this that it is never safe to plan a picnic for to-morrow based upon the predictions of to-day. The chief difficulty in the way of solving the great problems relating to the sudden changes in the weather and temperature lies in the fact that two-thirds or more of the earth's surface is covered with water; thus making it impossible to establish stations for observations that would be evenly distributed all over the earth's surface. Enough is known, however, to make the study of meteorology a most wonderfully interesting subject.

Air is composed chiefly of a mixture of oxygen and nitrogen, with a small amount of carbon dioxide. So far as the life and health of the animal is concerned we could get along without this latter substance, but it seems to be a necessity in the growth of vegetation. There are other things in the air which, while they are unnecessary for breathing purposes, it will be well for us to understand, as some of them are things to be avoided rather than inhaled.

As before mentioned, air contains moisture, which is a very variable quantity. In a cold day in winter it is not more than

one-thousandth part, while in a warm day in summer it may equal one-fortieth of the quantity of air in a given space. There is also a small amount of ammonia, perhaps not over one-sixty-millionth. Oxygen also exists in the air in very small quantities in another form called ozone. One way to produce ozone is by passing an electric spark through air. Any one who has operated a Holtz machine has noticed a peculiar smell attending the disruptive discharges, which is the odor of ozone. It is what chemists call an allotropic form of oxygen, just as the diamond, graphite, and charcoal are all different forms of carbon, and yet the chemical differences are scarcely traceable. It is more stimulating to breathe than oxygen, and is probably produced by lightning discharges.

The oxygen of the air is consumed by all processes of combustion, and in this we include the breathing of men and animals and the decay of vegetable matter, as well as the more active combustion arising from fires. A grown person consumes something over four hundred gallons of oxygen per day, and it is estimated that all the fires on the earth consume in a century as much oxygen as is contained in the air over an area of seventy miles square. All of these processes are throwing into the air carbon dioxide (carbonic acid), which, however, is offset by the power of vegetation to absorb it; thus the carbon is retained and forms a part of the woody fiber, and pure oxygen is given back into the air. By this process the normal conditions of the air are maintained.

One decimeter (nearly four inches) square of green leaves will decompose in one hour seven cublic centimeters of carbon dioxide, if the sun is shining on them; in the shade the same area will absorb about three in the same time.

The air contains another substance called bacteria in the form of vegetable germs. At one time these were supposed to be low forms of animal life, but it is now determined that they are the lowest forms of vegetable germs. Bacteria is the general or generic name for a large class of germs, many of them disease germs. By analysis of the air in different locations and in different parts of the country it has been determined that on the ocean and on the mountain tops these germs average only

one to each cubic yard of air. In the streets of the average city there are 3,000 of them to the cubic yard, while in other places where there is sickness, as in a hospital ward, there may be as many as 80,000 to the cubic yard. These facts go to prove what has long been well known, that the air of a city furnishes many more fruitful sources for disease than that of the country. Some forms of bacterial germs are not considered harmful, and they probably perform even a useful service in the economy of nature. Within certain limits, other things being equal, the higher one's dwelling is located above the common level the purer will be the air. This rule, however, has its limits, as the oxygen of the air is heavier than the nitrogen, so that the air at very great altitudes has not the same proportion of oxygen to nitrogen that it has at a lower level. An analysis that was made some years ago of the air on the west shore of Lake Michigan, especially that section where the bluffs are high, shows that it compares favorably with that of any other portion of the United States.

In view of the foregoing, it is of the highest importance to the sanitary condition of any city, town, or village that it be not too compactly built. If more than a certain number of people occupy a given area, it is absolutely impossible to preserve perfect sanitary conditions. And there ought to be a State law, especially for all suburban towns, which are the homes and sleeping places for large numbers of business men who spend their days in the foul air of the city, stipulating that the houses shall be not less than a certain distance apart. Oxygen is the great purifier of the blood, and if one does not get enough of it he suffers, even though he breathes no impurities. The power to resist the effects of bad air is much greater when one is awake and active than when asleep, and this is why it is more important to sleep in pure air than to be in it during our waking hours. It is best, however, to be in good air all of the time. By pure air I do not mean pure oxygen, but the right mixture of the two gases that make air. Too much of a good thing is often worse that not enough. Pure food to eat, pure water to drink, and pure air to breathe would soon be the financial ruin of a large class of doctors.

PHYSICAL GEOGRAPHY

Wind—Why It Blows

By ELISHA GRAY

GLOBULES of moisture, released by the action of the sun's rays in the process of evaporation, tend to rise, because they are lighter than the air. All material substances have weight; even hydrogen, the lightest known gas, has weight, and is attracted by gravitation. If there were no air or other gaseous substances on the face of the earth except hydrogen, it would be attracted to and envelop the earth the same as the air now does. Carbon dioxide is a gas that is heavier than the air. If we take a vessel filled with this gas and pour it into another vessel it will sink to the bottom and displace the air contained in it until the air is all driven out. If we fill a jar with water up to a certain height and then pour a pint of shot into it the water will be caused to rise in the vessel because it has been displaced at the bottom by the heavier material. Now if we remove the shot, the water will recede to the level maintained before the shot was put in. On the contrary, if we should pour an equal bulk of cork or pith balls into the jar, the water would not be displaced, because the balls are lighter than the water and would lie on top of it; if, however, the water is removed from the jar, the cork will immediately go to the bottom of the jar, because the cork is heavier than the air which has taken the place of the water. We wish to impress upon the mind of the reader the fact, that all substances of a fluid nature, whether in the fluid or gaseous state, have weight, and obey the laws of gravity, while the heavier portions will always seek the lower levels, and in doing this will displace the lighter

portions, causing them to rise. There is no tendency in any substance to rise of itself, but the lighter substance rises because it is forced to do so by the heavier, which displaces it. This law lies at the bottom of all the phenomena of air currents.

If we are at certain points on the seashore in the summer time we may notice that about nine o'clock in the morning a breeze will spring up from the ocean and blow toward the land; this will increase in intensity until about two o'clock in the afternoon, when it has reached its maximum velocity, and from this time it gradually diminishes, until in the evening there will be a season of calm, the same as there was in the early morning. The explanation of this peculiar action of the air is found in the fact that during the day the land is heated much more rapidly on its surface than the water is.

The radiant energy from the sun is suddenly arrested at the surface of the earth, which is heated to only a very shallow depth, while in the water it is different; being transparent it is penetrated by the radiant energy to a much greater depth and does not suddenly arrest it, as is the case on land. As the sun rises and the rays strike in a more and more vertical direction, the earth becomes rapidly and intensely heated at its surface, and this in turn heats the stratum of air next above it, which is pressing on it with a force of fifteen pounds to the square inch at sea-level. When air is heated it expands, and as it expands it grows lighter. The stratum lying upon the earth as soon as it becomes heated moves upward and its place is occupied by the heavier, cooler air that flows in from the sides. We can now see that if there is a strong ascending current of air on the land near the ocean the cooler air from the surface of the ocean will flow in to take the place of the warmer and lighter air that is driven upward, really by the force of gravity which causes the heavier fluid to keep the lowest level. As the earth grows hotter this movement is more and more rapid, which causes the flow of colder air to be quickened, and hence the increasing force of the wind as the sun mounts higher in the heavens. But when it has passed the point of maximum heating intensity and the earth begins to cool by radiation, the movements of air currents begin to slow up, until along in the

evening a point is reached where the surface of the earth and that of the ocean are of equal temperature, and there is no longer any cause for change of position in the air.

The earth heats up quickly, and it also cools quickly, especially if there is green grass and vegetation. While they are poor conductors of heat, they are excellent radiators, so that when the sun's rays are no longer active the earth cools down rapidly and soon passes the point where there is an equilibrium between the land and water. The water possesses the opposite quality. It is slow to become heated, because of a much larger mass that is affected, and is equally slow to give up the heat. And the consequence is, that after the sun has set the land cools so much faster than the water that we soon have the opposite condition, and the sea is warmer than the land, which makes the air at that point lighter, and which in turn causes the denser or colder air from the land to flow toward the ocean, and displace the lighter air and force it upward; hence we have a land instead of a sea breeze. So that the normal condition in summer is that of a breeze from the ocean toward the land during part of the day and a corresponding breeze from the land to the ocean during part of the night, with a period of no wind during the morning and evening of each day.

The forces that work to produce all the varying phenomena of air currents on different portions of the earth are difficult to explain, as there are so many local conditions of heat and cold, and these are modified by the advancing and receding seasons. The unequal distribution of land and water upon the earth's surface; the readiness with which some portions absorb and radiate heat as compared with others; the tall ranges of mountains, many of them snow-capped; the lowlands adjacent to them that become intensely heated under the sun's rays; the diversity of coast-line and the fact that there is a zone of continually heated earth and water in the tropical regions—all these conditions, coupled with the fact that the earth rotates on its axis once in twenty-four hours, are certainly sufficient to account for all the complicated phenomena of aerial changes on the various portions of the earth's surface.

The trade winds are so called because they blow in a certain

definite direction during certain seasons of the year, and can be reckoned upon for the use of commerce. If you trace the line of the equator you will notice that for more than three-quarters of the distance it passes through the water. The water becomes gradually heated to a considerable depth, and when once saturated with heat is slow to give it up. It can easily be seen that there will be a zone extending each way from the equator for a certain distance that will become more intensely heated than any other parts of the earth, with the exception of certain circumscribed portions of the land. The result is that this heated equatorial zone is constantly sending up warm air caused by the inrush of colder air, which is heavier than the air at the equator, expanded by the heat. The warm air at the equator is forced up into higher regions of the atmosphere, and here it overflows each way, north and south, causing a current of air in the upper regions counter to that of the lower. As it travels north and south it gradually drops as it becomes cooler, and finally at some point north and south its course is changed and it flows in again toward the equator. As a matter of fact, the trade winds do not flow apparently from the north and south directly toward the equator, but in an oblique direction. On the north side of the equator we have a northeasterly wind, and a southeasterly wind on the south side. This is caused by the rotation of the earth from west to east. The direction of the trade wind, however, is more apparent than real.

The earth in its diurnal revolutions travels at the rate of a little more than 1,000 miles an hour at the equator. But if we should travel northward to within four miles, say, of the north pole, the surface point would be moving at the rate of only about a mile an hour. At some point equidistant between the north pole and the equator the surface of the earth will be moving at a rate, say, of five hundred miles an hour. If we could fire a projectile from this point that would have a carrying power to take it to the equator some time after the projectile was fired, although it would fly in a perfectly direct line, it would appear to any one at the equator to be moving from a northeasterly direction. The reason is that the earth is travel-

ing twice as fast at the equator as it is at the point whence the projectile is fired. Therefore it will overshoot, so to speak, at the equator, and not be dragged around by the increased motion we find there.

To make this still plainer, suppose the earth to be standing still and a projectile be fired directly across from the north pole in the direction of the lines of longitude and required one hour to reach the equator, the projectile would appear to any one standing at the equator to come directly from the north. If, however, the earth is revolving to the eastward at the rate of 1,000 miles an hour at the equator, and the projectile was fired from the pole, where there is practically no motion, in the same direction along the longitudinal lines as before, the observer would have to be in a position of the equator 1,000 miles west of this longitudinal line, in order to see the projectile when it arrived; therefore the apparent movement of the projectile would not be along the line at the instant that it was fired, but along a line that would cross the equator at a point 1,000 miles west. When a southward impulse is given to the air it follows, to some extent, the same law, so that to one standing on the equator the northern trade wind will blow from the northeast and the southern trade wind from the southeast.

Owing to the fact that the air rises in the heated zone there is always a region of calms at this point where there is no wind and no rain. There are two other regions of calms in the ocean, one at the north at the tropic of Cancer and another at the south near the tropic of Capricorn. As has been stated, there are currents flowing back in the upper regions at the equator north and south, and these are called the upper trades —the lower currents being called the lower trades. These upper trades gradually fall till they reach the tropic of Cancer on the north, where the lower part of the current stops and bends back toward the equator, now becoming a part of the lower trade wind. This causes a calm at that point where it turns. The upper parts of this current continue on, in a northerly and southerly direction, on the surface until they meet with the cold air of the north and south polar regions,

where there is a conflict of the elements—as there always is when cold and warm currents meet.

The only point where the trade wind has free play is in the South Indian Ocean, and this is called the "heart of the trades."

If the whole globe were covered with water there would be a more constant condition of temperature; but owing to the great difference between the land and water, both as to altitude and the ability to absorb and radiate heat, we have all of these varied and complicated conditions of wind and weather. The trade winds shift from north to south and vice versa with the advancing and receding seasons, due to the fact that the earth has a compound motion. It not only revolves on its axis once in twenty-four hours, but it also travels around the sun once a year; and because the axis of the earth is not perpendicular to the plane of its orbit around the sun, the earth seems to rock back and forth in the direction of its axis once a year. This is only apparent, however, and not real.

PHYSICAL GEOGRAPHY

Mirage

By ELISHA GRAY

A LIGHT-RAY in passing from one transparent medium to another, differing in density, is bent at the point it enters. This bending of the light-ray is called refraction. If we put a stick into the water at an angle with its surface the stick will appear to bend upward at the point it enters the water, while the light-ray really bends downward.

To illustrate this phenomenon place a tank, something like an aquarium, filled with water, in a dark room. Admit a small beam of sunshine through the shutter, striking the top of the water at an angle, say, of forty-five degrees. If the room is dark you can see the beam of light as it passes through the air, for it illuminates the particles of dust floating in the air. When it strikes the surface of the water it is bent downward. Now let us put a coin on the bottom of the tank just where the beam of light strikes it, and put a screen of some opaque substance on the side of the tank from which the beam of light comes, and raise it up till it just touches the lower edge of the light-ray. Stretch a string along the path of the beam of light and fasten it at both ends—so as to mark its angle and position. Now open the shutter and flood the room with light; place your eye in the path of the beam that is now marked by the string and you can see the coin at the bottom of the tank, although it is really hidden by the screen, if you look toward it in a straight line. The coin will appear to be in a direct line with the string, but it is not.

Leave the string, coin, and screen in position, and run the

water off, and then place your eye in the same position as before when you saw the coin, and you will find that you cannot see it, for it is hidden behind the screen. Draw a line to the bottom of the tank in line with the string, and the point where it strikes the bottom is where the coin appeared to be. Place another coin at this point so that you can just see it over the top of the screen if you look from the same point as before. Now fill the tank with water again and look from the same view-point, and lo! the first coin has come into view in line with the string, while the second has moved forward out of line with the string. You observe, then, that by this means we can see around a corner. But the object under these conditions is never where it appears to be, for it will always appear to be in a direct line with the direction that the light-ray—that is reflected from the object—enters the eye.

Light is refracted differently in different media. It is refracted as it passes through the air unless the air is the same density all the way from the object to the eye. If we are looking through the air and there is a gradual change of density between us and the object we see, there will be a gradual curve in the reflected light coming from the object to us, and the object will appear to be in the direction that the light enters our eyes. The distance its true position will be from where it appears to be will depend upon the amount of change in the density of the media through which we are looking. This phenomenon we call mirage. Many times those of us who live on the lakeshore have seen this phenomenon when looking off on the horizon on a summer day. Sometimes the sand-hills of Michigan City, on the east shore of Lake Michigan, may be seen from the opposite shore looming up in the air, when in fact a straight line drawn from a point on the shore at Michigan City and elevated just enough to clear the surface of the water would clear the tree-tops on the opposite shore. So that when we see the sand-hills from the west shore we see by curved rays of light extending across the lake. Sometimes an image of the water-line on the horizon will be thrown up into the air with perhaps a picture of a ship on it, and often we can see the sky under the ship-picture, but not the ship itself, of which that

is a reflection. Many times we see the sun after it is below the horizon, by these refracted rays.

There is another phenomenon called mirage, that may be seen on sandy plains or deserts on any very hot day. The sand becomes very much heated, and a stratum of heated air is formed close to the ground which makes the density of the air increase upward, for a distance, forming a line of condensation which acts as a reflecting surface for light, and it has the appearance of smooth water. Any one seeing it for the first time will declare that it is water, and in fact the deception is perfect, as I have occasion to know. I was once traveling through what is called Smoky Valley, in Nevada, on a hot day. About two o'clock in the afternoon we came in sight of a large body of water many miles in extent, as it appeared to me. It was a lake of wondrous beauty, with a smooth surface. The mountains and trees were reflected in the water in inverted position, as all of us have seen in other bodies of smooth water. I imagined that I could see towns and cities scattered along the distant shores, and the deception was so perfect that for the time I could not believe it was not what it seemed. My companions were natives, and, knowing that I was a "tenderfoot," were disposed to have a little fun; and they had it. They had names for the towns, as well as the lake, and I got a lot of information regarding the industries carried on there. I could discern sails in the haze of the distance, and imagined I could see moving trains and hear the whistle of locomotives. After I had enjoyed this spectacle for an hour or more, as we jogged slowly along in our wagon, and the natives had had untold fun in a quiet way, the whole thing suddenly picked itself up and got out of sight. I knew then that I had been witnessing an unusually fine exhibition of mirage on the desert.

There is another kind of mirage that is much more common than the natural phenomena that I have been describing, and while it does not strictly belong in the category of natural science, there is a sense in which it does. It may be styled mental mirage, and consists in the distorted conceptions of various subjects and things that we see through a distorted mental atmosphere, which is largely one of our own creation.

THOMAS A. EDISON IN HIS LABORATORY.

Man is to a large extent a creature of circumstances and environment; not wholly, as that would take away his free agency and make him in no sense the architect of his own fortune. Every man of strong individuality is the latter, to a large extent, but he is a strong man indeed who can successfully resist, first, the molding influence of heredity, and after that the almost irresistible power of education in any particular line. He cannot entirely resist the prejudices of early training and surroundings, whether they appeal to his reasoning powers or not. This is especially true when applied to the dogmas of religious sects and the so-called principles of political parties. The average good citizen of any religious sect or political party sees clearly, in common with his brethren of other sects and parties, in direct lines through the atmosphere of common interest, common brotherhood, and sometimes common sense. But as soon as the rays of his mental vision strike some denser, or, it may be, rarer medium of prejudice of party, church, or society affiliation, a refraction takes place, and we have the phenomenon of mental mirage. The truth may lie in a direct line ahead, but he is really seeing in a different direction because of the refracting or distorting power of a prejudice.

Science has no prejudices—though scientists often do. Science is like figures: they do not lie themselves, but the men who figure are often the greatest liars in the world. Science, *per se*, is formulated truth. Its aim is to get at the truth about everything. Taking this view of science, it is the most important study that man ever engaged in. So much of human effort has been and is spent in combating things that are non-essential, that too little co-operative work is done in the direction of determining the great essential truths. In one of the chapters on Sound it was shown how one musical tone of the same power and pitch, and even of the same quality, as that of another just like it, might be entirely obliterated by the manner in which they were sounded in relation to each other. It was also shown that there was an easier way to sound both together so that each would re-enforce the other and thus double the tone instead of the one entirely destroying the efficiency of the other. So it is with human effort. Co-operation will ac-

complish wonders for good, while the opposite only leaves a dark void that is the darker because of the misguided effort put forth, that other men have not only seen, but of which they have also felt the blighting influence.

Another phase of mirage, as seen in natural phenomena, is its complete deceptiveness and its ability, owing to the peculiar atmosphere by which it is surrounded, to stimulate the imagination. In the hazy outlines ghosts of shapes become real things, and the heated wave-motion of the atmosphere easily gives life to imaginary men and animals and motion to sailing vessels and steam-cars. Mental mirage is more potent in its deceptiveness and more powerful in its influence over the imagination than its counterpart in the natural world; and has the disadvantage of not yielding so readily to the power of analysis and being so susceptible of explanation. One of the great advantages derived from the study of natural science is, that it is usually studied for its own sake and for the object of arriving at the truth whatever it is. The scientific investigator must have no prejudice not founded on fact, and when so founded it is no longer a prejudice. He must not allow the religious dogma or the political principle to enter or become one of the factors in his search for truth, but when he has found the truth it may shape the dogma, destroy or confirm the political principle, according as they are found to be in or out of harmony with the facts. Facts are stubborn things, and it is worse than useless to try to ignore them when once established. The man who uses scientific methods in studying all questions is a much safer man to follow than the man who starts out with certain preconceived notions of things. The former throws away all prejudice in his investigations, while the latter is constantly trying to find something to bolster up his preconceived notions. He generally thinks he finds what he is seeking for, but he usually finds them through the refracted vision of mental mirage.

PHYSICAL GEOGRAPHY

Rain and Snow

By JOHN TYNDALL

AT the equator, and within certain limits north and south of it, the sun at certain periods of the year is directly overhead at noon. These limits are called the Tropics of Cancer and of Capricorn. Upon the belt comprised between these two circles the sun's rays fall with their mightiest power; for here they shoot directly downward, and heat both earth and sea more than when they strike slantingly.

When the vertical sunbeams strike the land they heat it, and the air in contact with the hot soil becomes heated in turn. But when heated the air expands, and when it expands it becomes lighter. This lighter air rises, like wood plunged into water, through the heavier air overhead.

When the sunbeams fall upon the sea the water is warmed, though not so much as the land. The warmed water expands, becomes thereby lighter, and therefore continues to float upon the top. This upper layer of water warms to some extent the air in contact with it, but it also sends up a quantity of aqueous vapor, which being far lighter than air, helps the latter to rise. Thus both from the land and from the sea we have ascending currents established by the action of the sun.

When they reach a certain elevation in the atmosphere, these currents divide and flow, part toward the north and part toward the south; while from the north and the south a flow of heavier and colder air sets in to supply the place of the ascending warm air.

Incessant circulation is thus established in the atmosphere.

The equatorial air and vapor flow above toward the north and south poles, while the polar air flows below toward the equator. The two currents of air thus established are called the upper and the lower trade winds.

But before the air returns from the poles great changes have occurred. For the air as it quitted the equatorial regions was laden with aqueous vapor, which could not subsist in the cold polar regions. It is there precipitated, falling sometimes as rain, or more commonly as snow. The land near the pole is covered with this snow, which gives birth to vast glaciers.

It is necessary that you should have a perfectly clear view of this process, for great mistakes have been made regarding the manner in which glaciers are related to the heat of the sun

It was supposed that if the sun's heat were diminished, greater glaciers than those now existing would be produced. But the lessening of the sun's heat would infallibly diminish the quantity of aqueous vapor, and thus cut off the glaciers at their source. A brief illustration will complete your knowledge here.

In the process of ordinary distillation, the liquid to be distilled is heated and converted into vapor in one vessel, and chilled and reconverted into liquid in another. What has just been stated renders it plain that the earth and its atmosphere constitute a vast distilling apparatus in which the equatorial ocean plays the part of the boiler, and the chill regions of the poles the part of the condenser. In this process of distillation *heat* plays quite as necessary a part as *cold,* and before Bishop Heber could speak of "Greenland's icy mountains," the equatorial ocean had to be warmed by the sun. We shall have more to say upon this question afterward.

The heating of the tropical air by the sun is *indirect.* The solar beams have scarcely any power to heat the air through which they pass; but they heat the land and ocean, and these communicate their heat to the air in contact with them. The air and vapor start upward charged with the heat thus communicated.

Tropical Rains

But long before the air and vapor from the equator reach the poles, precipitation occurs. Wherever a humid warm wind mixes with a cold dry one, rain falls. Indeed the heaviest rains occur at those places where the sun is vertically overhead. We must inquire a little more closely into their origin.

Fill a bladder about two-thirds full of air at the sea level, and take it to the summit of Mount Blanc. As you ascend, the bladder becomes more and more distended; at the top of the mountain it is fully distended, and has evidently to bear a pressure from within. Returning to the sea level you find that the tightness disappears, the bladder finally appearing as flaccid as at first.

The reason is plain. At the sea level the air within the bladder has to bear the pressure of the whole atmosphere, being thereby squeezed into a comparatively small volume. In ascending the mountain, you leave more and more of the atmosphere behind; the pressure becomes less and less, and by its expansive force the air within the bladder swells as the outside pressure is diminished. At the top of the mountain the expansion is quite sufficient to render the bladder tight, the pressure within being then actually greater than the pressure without. By means of an air-pump we can show the expansion of a balloon partly filled with air, when the external pressure has been in part removed.

But why do I dwell upon this? Simply to make plain to you that the *unconfined air*, heated at the earth's surface, and ascending by its lightness, must expand more and more the higher it rises in the atmosphere.

And now I have to introduce to you a new fact, toward the statement of which I have been working for some time. It is this: *The ascending air is chilled by its expansion.* Indeed this chilling is one source of the coldness of the higher atmospheric regions. And now fix your eye upon those mixed currents of air and aqueous vapor which rise from the warm tropical ocean. They start with plenty of heat to preserve the vapor

as vapor; but as they rise they come into regions already chilled, and they are still further chilled by their own expansion. The consequence might be foreseen. The load of vapor is in great part precipitated, dense clouds are formed, their particles coalesce to rain-drops, which descend daily in gushes so profuse that the word "torrential" is used to express the copiousness of the rainfall. I could show you this chilling by expansion, and also the consequent precipitation of clouds.

Thus, long before the air from the equator reaches the poles, its vapor is in great part removed from it, having redescended to the earth as rain. Still a good quantity of the vapor is carried forward, which yields hail, rain, and snow in northern and southern lands.

Mountain Condensers

To complete our view of the process of atmospheric precipitation we must take into account the action of mountains. Imagine a southwest wind blowing across the Atlantic toward Ireland. In its passage it charges itself with aqueous vapor. In the south of Ireland it encounters the mountains of Kerry; the highest of these is Magillicuddy's Reeks, near Killarney. Now the lowest stratum of this Atlantic wind is that which is most fully charged with vapor. When it encounters the base of the Kerry mountains it is tilted up and flows bodily over them. Its load of vapor is therefore carried to a height, it expands on reaching the height, it is chilled in consequence of the expansion, and comes down in copious showers of rain. From this, in fact, arises the luxuriant vegetation of Killarney; to this, indeed, the lakes owe their water supply. The cold crests of the mountains also aid in the work of condensation.

Note the consequence. There is a town called Cahirciveen to the southwest of Magillicuddy's Reeks, at which observations of the rainfall have been made, and a good distance farther to the northeast, right in the course of the southwest wind there is another town, called Portarlington, at which observations of rainfall have also been made. But before the wind reaches the latter station it has passed over the mountains of Kerry and left a great portion of its moisture behind it. What is the re-

sult? At Cahirciveen, as shown by Dr. Lloyd, the rainfall amounts to fifty-nine inches in a year, while at Portarlington it is only twenty-one inches.

Again, you may sometimes descend from the Alps when the fall of rain and snow is heavy and incessant, into Italy, and find the sky over the plains of Lombardy blue and cloudless, the wind at the same time *blowing over the plain toward the Alps*. Below, the wind is hot enough to keep its vapor in a perfectly transparent state; but it meets the mountains, is tilted up, expanded, and chilled. The cold of the higher summits also helps the chill. The consequence is that the vapor is precipitated as rain or snow, thus producing bad weather upon the heights, while the plains below, flooded with the same air, enjoy the aspect of the unclouded summer sun. Clouds blowing *from* the Alps are also sometimes dissolved over the plains of Lombardy.

In connection with the formation of clouds by mountains, one particularly instructive effect may be here noticed. You frequently see a streamer of cloud many hundred yards in length drawn out from an Alpine peak. Its steadiness appears perfect, though a strong wind may be blowing at the same time over the mountain head. Why is the cloud not blown away? It *is* blown away; its permanence is only apparent. At one end it is incessantly dissolved; at the other end it is incessantly renewed: supply and consumption being thus equalized, the cloud appears as changeless as the mountain to which it seems to cling. When the red sun of the evening shines upon these cloud-streamers they resemble vast torches with their flames blown through the air.

Architecture of Snow

We now resemble persons who have climbed a difficult peak, and thereby earned the enjoyment of a wide prospect. Having made ourselves masters of the conditions necessary to the production of mountain snow, we are able to take a comprehensive and intelligent view of the phenomena of glaciers.

A few words are still necessary as to the formation of snow.

The molecules and atoms of all substances, when allowed free play, build themselves into definite and, for the most part, beautiful forms called crystals. Iron, copper, gold, silve·· lead, sulphur, when melted and permitted to cool gradually, all show this crystallizing power. The metal bismuth shows it in a particularly striking manner, and when properly fused and solidified, self-built crystals of great size and beauty are formed of this metal.

If you dissolve saltpetre in water, and allow the solution to evaporate slowly, you may obtain large crystals, for no portion of the salt is converted into vapor. The water of our atmosphere is fresh though it is derived from the salt sea. Sugar dissolved in water, and permitted to evaporate, yields crystals of sugar-candy. Alum readily crystallizes in the same way. Flints dissolved, as they sometimes are in nature, and permitted to crystallize, yield the prisms and pyramids of rock crystal. Chalk dissolved and crystallized yields Iceland spar. The diamond is crystallized carbon. All our precious stones, the ruby, sapphire, beryl, topaz, emerald, are all examples of this crystallizing power.

You have heard of the force of gravitation, and you know that it consists of an attraction of every particle of matter for every other particle. You know that planets and moons are held in their orbits by this attraction. But gravitation is a very simple affair compared to the force, or rather forces, of crystallization. For here the ultimate particles of mattter, inconceivably small as they are, show themselves possessed of attractive and repellent poles, by the mutual action of which the shape and structure of the crystal are determined. In the solid condition the attracting poles are rigidly locked together; but if sufficient heat be applied the bond of union is dissolved, and in the state of fusion the poles are pushed so far asunder as to be practically out of each other's range. The natural tendency of the molecules to build themselves together is thus neutralized.

This is the case with water, which as a liquid is to all appearance formless. When sufficiently cooled the molecules are brought within the play of the crystallizing force, and they then arrange themselves in forms of indescribable beauty.

When snow is produced in calm air, the icy particles build themselves into beautiful stellar shapes, each star possessing six rays. There is no deviation from this type, though in other respects the appearances of the snow-stars are infinitely various. In the polar regions these exquisite forms were observed by Dr. Scoresby, who gave numerous drawings of them. I have observed them in mid-winter filling the air, and loading the slopes of the Alps. But in England they are also to be seen, and all words of mine must fail to convey an impression of their vivid beauty.

It is worth pausing to think what wonderful work is going on in the atmosphere during the formation and descent of every snow-shower; what building power is brought into play! and how imperfect seem the productions of human minds and hands when compared with those formed by the blind forces of nature!

But who ventures to call the forces of nature blind? In reality, when we speak thus we are describing our own condition. The blindness is ours; and what we really ought to say, and to confess, is that our powers are absolutely unable to comprehend either the origin or the end of the operations of nature.

But while we thus acknowledge our limits, there is also reason for wonder at the extent to which science has mastered the system of nature. From age to age, and from generation to generation, fact has been added to fact, and law to law, the true method and order of the Universe being thereby more and more revealed. In doing this science has encountered and overthrown various forms of superstition and deceit, of credulity and imposture. But the world continually produces weak persons and wicked persons; and as long as they continue to exist side by side, as they do in this our day, very debasing beliefs will also continue to infest the world.

Atomic Poles

"What did I mean when, a few moments ago I spoke of attracting and repellent poles?" Let me try to answer this question. You know that astronomers and geographers speak

of the earth's poles, and you have also heard of magnetic poles, the poles of a magnet being the points at which the attraction and repulsion of the magnet are as it were concentrated.

Every magnet possesses two such poles; and if iron filings be scattered over a magnet, each particle becomes also endowed with two poles. Suppose such particles devoid of weight and floating in our atmosphere, what must occur when they come near each other? Manifestly the repellent poles will retreat from each other, while the attractive poles will approach and finally lock themselves together. And supposing the particles, instead of a single pair, to possess several pairs of poles arranged at definite points over their surfaces; you can then picture them, in obedience to their mutual attractions and repulsions, building themselves together to form masses of definite shape and structure.

Imagine the molecules of water in calm cold air to be gifted with poles of this description, which compel the particles to lay themselves together in a definite order, and you have before your mind's eye the unseen architecture which finally produces the visible and beautiful crystals of the snow. Thus our first notions and conceptions of poles are obtained from the sight of our eyes in looking at the effects of magnetism; and we then transfer these notions and conceptions to particles which no eye has ever seen. The power by which we thus picture to ourselves effects beyond the range of the senses is what philosophers call the Imagination, and in the effort of the mind to seize upon the unseen architecture of crystals, we have an example of the "scientific use" of this faculty. Without imagination we might have *critical* power, but not *creative* power in science.

Architecture of Lake Ice

We have thus made ourselves acquainted with the beautiful snow-flowers self-constructed by the molecules of water in calm, cold air. Do the molecules show this architectural power when ordinary water is frozen? What, for example, is the structure of the ice over which we skate in winter? Quite as wonderful as the flowers of the snow. The observation is rare, if not

new, but I have seen in water slowly freezing six-rayed ice-stars formed, and floating free on the surface. A six-rayed star, moreover, is typical of the construction of all our lake ice. It is built up of such forms wonderfully interlaced.

Take a slab of lake ice and place it in the path of a concentrated sunbeam. Watch the track of the beam through the ice. Part of the beam is stopped, part of it goes through; the former produces internal liquefaction; the latter has no effect whatever upon the ice. But the liquefaction is not uniformly diffused. From separate spots of the ice little shining points are seen to sparkle forth. Every one of those points is surrounded by a beautiful liquid flower with six petals.

Iee and water are so optically alike that unless the light falls properly upon these flowers you cannot see them. But what is the central spot? A vacuum. Ice swims on water because, bulk for bulk, it is ligher than water; so that when ice is melted it shrinks in size. Can the liquid flowers then occupy the whole space of the ice melted? Plainly no. A little empty space is formed with the flowers, and this space, or rather its surface, shines in the sun with the luster of burnished silver.

In all cases the flowers are formed parallel to the surface of freezing. They are formed when the sun shines upon the ice of every lake; sometimes in myriads, and so small as to require a magnifying glass to see them. They are always attainable, but their beauty is often marred by internal defects of the ice. Every one portion of the same piece of ice may show them exquisitely, while a second portion shows them imperfectly.

Here we have a reversal of the process of crystallization. The searching solar beam is delicate enough to take the molecules down without deranging the order of their architecture. Try the experiment for yourself with a pocket-lens on a sunny day. You will not find the flowers confused; they all lie parallel to the surface of freezing. In this exquisite way every bit of the ice over which our skaters glide in winter is put together.

I said that a portion of the sunbeam was stopped by the ice and liquefied it. What is this portion? The dark heat of the sun. The great body of the light waves, and even a portion of the dark ones, pass through the ice without losing any of their

heating power. When properly concentrated on combustible bodies, even after having passed through the ice, their burning power becomes manifest.

And the ice itself may be employed to concentrate them. With an ice-lens in the polar regions Dr. Scoresby has often concentrated the sun's rays so as to make them burn wood, fire gunpowder, and melt lead; thus proving that the heating power is retained by the rays, even after they have passed through so cold a substance.

By rendering the rays of the electric lamp parallel, and then sending them through a lens of ice, we obtain all the effects which Dr. Scoresby obtained with the rays of the sun.

PHYSICAL GEOGRAPHY

Tides

By ELISHA GRAY

ANY one who has spent a summer at the seashore has observed that the water level of the ocean changes twice in about twenty-four hours, or perhaps it would be a better statement to say that it is continually changing, and that twice in twenty-four hours there is a point when it reaches its highest level and another when it reaches its lowest. It swings back and forth like a pendulum, making a complete oscillation once in twelve hours. When we come to study this phenomenon closely we find that it varies each day, and that for a certain period of time the water will reach a higher level each succeeding day until it culminates in a maximum height, when it begins to gradually diminish from day to day until it has reached a minimum. Here it turns and goes over the same round again. It will be further observed that the time occupied between one high tide and the next one is a trifle over twelve hours. That is to say, the two ebbs and flows that occur each day require a little more than twenty-four hours, so that the tidal day is a little longer than the solar day. It corresponds to what we call the lunar day.

The moon goes through all its phases once in twenty-eight days. The tide considered in its simplest aspect is a struggle on the part of the water to follow the moon. There is a mutual attraction of gravitation between the earth and the moon. Because the water of the earth is mobile it tends to pile up at a point nearest the moon. But the earth as a whole also moves toward the moon, and more than the water does, keeping its

round shape, while its movable water (practically enveloping it) is piled up before it toward the moon and left accumulated behind it away from the moon. So that in a rough way it is a solid round earth, surrounded by an oval body of water: the long axis of the oval representing the high tides, which, as they follow the moon, slide completely around the earth once in every twenty-four hours. Thus, there are really two high tides and two low tides moving around the earth at the same time; and this accounts for the two daily tides.

We have accounted for the time when they occur in the fact that the water attempts to follow the moon, but this does not account for the gradual changes in the amount of fluctuation from day to day. The problem is complicated by the fact that the sun also has an attraction for the earth as well as the moon. But from the fact that the sun is something like four hundred times farther from the earth than the moon is, and also the fact that the attraction of one body for another varies inversely as the square of the distance, the moon has an immense advantage over the sun, although so much smaller. If the power of the moon were entirely suspended, or if the moon were blotted out of existence, there would still be a tide. The fluctuation between high and low tide would not be nearly so great as it is at present, but it would occur at the same time each day, because it would be wholly a product of the sun.

It will be easily seen that these two forces acting upon the water at the same time will cause a complicated condition in the movement of the waters of the ocean. There will come a time once in twenty-eight days when the sun and the moon will act conjointly, and both will pull in the same direction at the same time upon the water. This joint action of the sun and moon produces the highest tide, which is called the "spring" tide. From this point, however, the tides will grow less each day, because the relation of the sun and moon is constantly changing, owing to the fact that it requires three hundred and sixty-five days for the sun to complete his apparent revolution around the earth, while the moon does her actual course in twenty-eight days. When the sun and moon have changed their relative positions so that they are at right angles to each

other with reference to the earth—at a quarter-circle apart—the sun and moon will be pulling against each other; at least this is the point where the moon is at the greatest disadvantage with reference to its ability to attract the water.

Because one-quarter around the earth the sun is creating his own tide, which to that extent counteracts the effect produced by the moon, the tide under the moon at this point is at its lowest point and is called the "neap" tide. When the moon has passed on around the earth to a point where it is opposite to that of the sun—at a half-circle apart—there will be another spring tide, and then another neap tide when it is on the last quarter, and from that point the tide will increase daily until it reaches the point where the sun and moon are in exact line with reference to the earth's center, when another spring tide occurs. From this it will be seen that there are two spring tides and two neap tides in each twenty-eight days. This is the fundamental law governing tides.

There are many other conditions that modify tidal effects. Neither the sun nor the moon is always at the same distance from the earth, so that there will be a variation, at times, in high and low tides. For instance, it will happen sometimes that when the sun and moon are acting conjointly they will both be at their nearest point to the earth, and when this is the case the spring tide will be much higher than usual.

For many years the writer has observed that artesian wells, made by deep borings of small diameter into the earth to a water supply, have a daily period of ebb and flow, as well as a neap and spring tide, the same as the tides of the ocean, except that the process is reversed. The time of greatest flow of an artesian well will occur at low tide in the ocean. This might be accounted for from the fact that when the tide is at its height the moon is also pulling upon the crust of the earth, which would tend to take the pressure off the sand rock which lies one or two thousand feet below the surface, and through which the flow of water comes, and thus slacken the flow. When the moon is in position for low tide, the crust of the earth would settle back and thus produce a greater pressure upon the water-bearing rock. This is the only theory that has

suggested itself to the writer that would seem to account for these phenomena.

Looked at from one standpoint, it is easy to account for tidal action. But when we attempt to make up a table giving the hour and minute as well as the height of the tide at that particular time we find that we have a very complicated mathematical problem. Tables are made out, however, so that we know at just what time in the day a tide will occur every day in the year.

PHYSICAL GEOGRAPHY

Why Ice Floats

By ELISHA GRAY

NATURE is full of surprises. By a long series of experimental investigations you think you have established a law that is as unalterable as those of the Medes and Persians. But once in a while you stumble upon phenomena that seem to contradict all that has gone before.

These, however, may be only the exceptions that prove the rule. It is recognized as a fundamental law that heat expands and cold contracts; that the atom when in a state of intense motion (which is the condition producing the effect that we call "heat") requires more room than when its motions are of a less amplitude. In other words, an increase in the amplitude of atomic motion is heating, while a decrease is cooling. It follows from the above statement that the colder a body becomes the smaller will be its dimensions. There are two or three, and perhaps more, exceptions to this rule, and the most notable one is that of water. Water follows the same law that all other substances do under the action of heat and cold, within certain limits only. If we take water, say at fifty degrees Fahrenheit and subject it to cold it will gradually contract in bulk until it reaches thirty-nine degrees Fahrenheit. At this point, very curiously, contraction ceases, and here we find the maximum density of water. If the temperature is still lowered we find the bulk is gradually increasing instead of diminishing (as is the rule with other fluids), and when it reaches the freezing point there is a sudden and marked expansion, so much so that a cubic foot of ice, which is solidified water, will not weigh

as much as a cubic foot of water before it freezes—hence it floats.

Let us try an experiment. Take a small glass flask, terminating in a long neck, say of four to six inches, and of small diameter. Suppose the water in the glass to be at fifty degrees Fahrenheit. Fill the flask with water until it stands halfway up the neck at fifty degrees temperature. Now immerse the flask gradually in hot water, and observe the effect. For a moment the water will lower in the neck of the tube, but this is due to the fact that the glass expands before the heat is communicated to the water and enlarges its capacity. But immediately the water will begin to rise as the heat is communicated to it, and will continue to expand up to the boiling point. Now take the flask out of the hot water and gradually introduce it into a freezing mixture made of broken ice and salt. Immediately the water will begin to fall in the tube, showing that it is contracting under the cold, and it will continue to contract until it reaches a temperature of thirty-nine degrees Fahrenheit, when it will come to a standstill and then proceed to expand as the temperature of the water lowers. When it reaches the freezing point the fluid can no longer rise in the neck of the flask, which is broken by the sudden expansion that takes place at this point.

To show what an irresistible power resides in the atoms of which the body is made, let us take an iron flask with walls one-half inch or more in thickness; fill it with water and seal it up by screwing on the neck an iron cap; now plunge it into the freezing mixture, and the first effect will be to contract the water unless it is already below thirty-nine degrees Fahrenheit, but when it reaches that point expansion sets in, and this continues to the freezing point, when a greatly increased expansion takes place suddenly. The walls of the iron flask, although a half-inch in thickness, are no longer able to resist the combined efforts of the billions upon billions of the atoms of which the water is made up, in their individual clamor for more room, hence the flask is shivered into pieces.

There are one or two other substances which are exceptions to the general rule, but we will mention only one, which is the

metal bismuth. If we should melt a sufficient amount to fill an iron flask such as we have described, and subject it to the same freezing process, the flask will be broken the same as in the experiment made with the water.

A query arises, Why this phenomenon? Why does water, in cooling, follow a different law from that of nearly all other substances?

This is a case where it is much easier to ask a question than to answer it. When water solidifies at the moment of freezing, crystallization sets in. But what is crystallization? Crystallization is a peculiar arrangement of the molecules of matter, which takes place in some substances when they pass from the liquid to the solid form. The molecules assume definite forms and shapes, according to the nature of the substance. When water assumes the solid form under the action of cold the molecules arrange themselves according to certain definite and fixed laws, the result of which is to increase the bulk to a considerable extent over that which the same number of molecules would occupy at a temperature of thirty-nine degrees Fahrenheit. Hence, as has been heretofore stated, a given block of solidified water is lighter than the same bulk would be in the fluid state, and this is the reason why ice floats.

What would happen in case nature did not make this exception to the laws of expansion and contraction by heat and cold, in the case of water? First, our lakes would freeze from the bottom upward; as soon as the surface became frozen, or even colder than the water underneath, it would drop to the bottom, the warmer water below coming up by a well-known law—that the warmer fluid rises and the colder falls. This circulation would continue until ice began to form, which would immediately drop to the bottom, and this process would go on until the whole mass were frozen solid. In the same way our rivers in the northern climates would freeze from the bottom, and in time our valleys would fill up with ice to a thickness that the summer's sun would never melt, and gradually all north of a certain zone would become a great glacier, rendering not only the lakes and rivers, but also the surface of the earth, unfitted for animal life.

PHYSICAL GEOGRAPHY

Franklin's Kite Modernized

By ALEXANDER McADIE

THE recent improvements in kites have suggested perhaps to many the question, "How would Franklin perform his kite experiment to-day?" It may seem a little presumptuous to speak for that unique philosopher, and attempt to outline the modifications he would introduce were he to walk on earth again and fly kites as of yore; for, with the exception of Jefferson, perhaps his was the most far-seeing and ingenious mind of a remarkable age. But the world moves; and in making kites, as well as in devising electrometers and apparatus for measuring the electricity of the air, great advances have been made. Franklin would enjoy repeating his kite experiment to-day, using modern apparatus. What changes and lines of investigation he would suggest are beyond conjecture.

A hundred and fifty years ago a ragged colonial regiment drew up before the home of its philosopher-colonel and fired an ill-timed salute in his honor. A fragile electrical instrument was shaken from a shelf and shattered. Franklin doubtless appreciated the salute and regretted the accident. In the course of his long life he received other salutes, as when the French Academy rose at his entrance; and he constructed and worked with other electrometers; but for us that first experience will always possess a peculiar interest. The kite and the electrometer betray the intention of the colonial scientist to explore the free air, and, reaching out from earth, study air electrification *in situ*. He made the beginning by identifying the lightning flash with the electricity developed by the frictional

machine of that time. A hundred patient philosophers have carried on the work, improving methods and apparatus, until to-day we stand upon the threshold of a great electrical survey of the atmosphere. It is no idle prophecy to say that the twentieth century will witness wonderful achievements in measuring the potential of the lightning flash, in demonstrating the nature of the aurora, and in utilizing the electrical energy of the cloud. The improved kite and air-runner will be the agency through which these results will be accomplished.

The famous kite experiment is described by Franklin in a letter dated October 19, 1752: "Make a small cross of light sticks of cedar, the arms so long as to reach to the four corners of a large, thin silk handkerchief when extended. Tie the corners of the handkerchief to the extremities of the cross, so you have the body of a kite which, being properly accommodated with a tail, loop, and string, will rise in the air like those made of paper, but being made of silk is better fitted to bear the wet and wind of a thunder-gust without tearing. To the top of the upright stick of the cross is to be fixed a very sharp-pointed wire rising a foot or more above the wood. To the end of the twine next the hand is to be tied a silk ribbon, and where the silk and twine join a key may be fastened. This kite is to be raised when a thunder-gust appears to be coming on, and the person who holds the string must stand within a door or window, or under some cover, so that the silk ribbon may not be wet; and care must be taken that the twine does not touch the frame of the door or window. As soon as the thunder-clouds come over the kite, the pointed wire will draw the electric fire from them, and the kite, with all the twine, will be electrified, and stand out every way and be attracted by an approaching finger. And when the rain has wet the kite and twine you will find the electric fire stream out plentifully from the key on the approach of your knuckle."

Now, how would we perform this experiment to-day and with what results? Having flown big kites during thunder-storms, it may perhaps be best to describe step by step two of these experiments, and then speak of what we know can be done, but as yet has not been done.

Our first repetition of Franklin's kite experiment was at Blue Hill Observatory, some ten miles southwest of Boston, one hundred and thirty-three years after its first trial. There were two large kites silk-covered and tin-foiled on the front face. These kites were of the ordinary hexagonal shape, for in 1885 Malay and Hargrave kites were all unknown to us. Fifteen hundred feet of strong hemp fish-line were wrapped loosely with uncovered copper wire of the smallest diameter suitable, and this was brought into a window on the east side of the observatory, through rubber tubing and blocks of paraffin. Pieces of thoroughly clean plate glass were also used. Materials capable of giving a high insulation were not so easily had then as now. We knew very little about mica; and quartz fibers and Mascart insulators could not be obtained in the United States. Our electrometer, however, was a great improvement upon any previous type, and far removed from the simple pith-ball device used by Franklin. Knowing that an electrified body free to move between two other electrified bodies will always move from the higher to the lower potential, Lord Kelvin devised an instrument consisting of four metallic sections, symmetrically grouped around a common center and inclosing a flat free-swinging piece of aluminum called a needle. The end of the kite wire is connected with the needle and the sections or quadrants are alternately connected and then electrified, one set with a high positive potential, say five hundred volts, and the other with a corresponding negative value, say five hundred volts lower than the ground.

Perhaps the most noteworthy result of these earlier experiments was the discovery (for such we think it was) that showery or thunder-storm weather was not the only condition giving marked electrical effects. The electrometer needle would be violently deflected and large sparks obtained at other times. Day after day as we flew the kite we found this high electrification of the air, and we had no trouble in getting sparks even when the sky was cloudless. One other discovery was made, and this would have delighted Franklin more than the other, for he was always most pleased when a practical application was in sight. Seated within the instrument room of the ob-

servatory, with his back to the open window through which came the kite wire carefully insulated, and the kite high in air, the observer closely watching the index of the electrometer could tell positively, and as quickly as one outside watching the kite, whether it rose or fell. When the kite rose, up went the voltage, and *vice versa*. In other words, the electric potential of the air increased with elevation. It must be confessed that the kites made to-day would have behaved better and flown with more steadiness than the one we used. It may have been the varying wind, or more likely wrong proportions in the kite and tail; but our old hexagonal kite would dive even when high in air. Once we kept the kite aloft from the forenoon until late at night, but that was something unusual.

Passing now over six years in which we had been busy measuring the electrification of the air under all conditions, and discovering, for example, that a snow-storm was almost identical with a thunder-storm in its tremendous electrical changes, we come to the year 1891, when we again flew kites for the purpose of electrically exploring the air. Our experiments at the top of the Washington Monument in 1885 and 1886 (especially those during severe thunder-storms, when we obtained potentials as high as three and four thousand volts just before the lightning), had given us an insight into the strains and stresses in the air, and taught us what to expect at such times. There was still little improvement in the kite, but much better electrical apparatus was at hand. It may seem ridiculous, but we hauled nearly a wagon-load of electrical apparatus to the summit of the hill, and found occasion to use all of it. Our insulators were delicate glass vessels, curiously shaped, containing sulphuric acid, and able to hold with little leakage the highest known potentials. Besides these fine Mascart insulators, we had hundreds of distilled-water batteries and two electrometers, one a Mascart quadrant, the other a large multiple quadrant. The chief aim that year was to secure by mechanical means (discarding the photographic and eye methods) a continuous record of the potential. When we can study the potential at any moment and still have a record of it, the relation of the electricity of the air to the pressure, temperature, and moisture

will be more easily investigated. Among our records that year there is one date, June 30, 1891, where a direct comparison of the electrification of the air fifteen or twenty feet from the ground and at a height of about five hundred feet is shown. In one, the potential was obtained by a water-dropper collector from a second-story window in the observatory, and in the other was obtained by means of the kite. It will be seen how much higher the kite values are, although the kite was a much slower accumulator of electricity. In the next year, 1892, the kite was flown several times during thunder-storms, but generally during afternoon storms; and in the lull preceding the wind rush the kite would fall. It was not until August 9th that we succeeded in going through a storm with the kite still flying. About 11 A.M. the kite was sent aloft, and it remained aloft until after 10 P.M. From the observatory one can see to the west fifty or more miles, and a thunder-storm came into view just about sunset. The kite was flying steadily, and whenever a finger was held near the kite-wire there was a perfect fusillade of sparks. As the darkness increased, the polished metallic and glass surfaces in the large electrometer reflected the sparks, now strong enough to jump across the air-gaps, and the incessant sizzling threatened to burn out the instrument. The vividness of the lightning in the west also made it plain that the storm was one of great violence, and as the observatory itself would be jeopardized, one of the four men present proposed to cut the wired string and let the kite go. But even that was easier said than done, for to touch the string was to receive a severe shock. It was necessary, however, to get out of the scrape, and one of the party took the kite-string and broke the connection with the electrometer and insulators. While he was in the act of doing this, the others, who by this time were outside the building, saw a flash of lightning to the west of the hill. The observer who was undoing the kite-wire did not see this flash. He saw a brilliant flare-up in the electrometer, and at the same instant felt a severe blow across both arms. Notwithstanding, he loosened the wire, and, dropping an end without, it took but a few moments to make it fast on the hillside some distance away from the observatory. There

it remained for the rest of the night. A 105-volt incandescent lamp was placed between the end of the kite-wire and a wire running to the ground. There was some light, but no incandescence of the filament. It was more in the nature of a creeping of the charge over the outer glass surface of the lamp. Stinging sparks were felt whenever the kite-wire was touched. The storm gradually passed over, the lightning being vivid and frequent in the west and north, and, as we learned next day, doing considerable damage. The nearest flash to the hill, however, as well as we could determine by the interval between thunder and flash, was 4,500 feet away, so that the discharge which the observer felt while loosening the wire must have been a sympathetic one. We obtained a photograph of the prime discharge, and very curiously this shows a remarkable change of direction.

This year, in some interesting experiments made on the roof of the Mills Building at San Francisco, it was noticed that the roof, which has a covering of bitumen, was a good insulator. Ordinarily one may touch the reel on which the kite-wire is wound without being shocked, but if a wire be connected with the ventilating pipes running to the ground there are small sparks. Introducing a condenser in the circuit, the intensity of the spark is increased. It only remains to construct an appropriate coil of the kite-wire and place within it another independent coil. In the outer coil a quick circuit-breaker may be placed, and theoretically at least we shall transform down the high potential and low amperage charge of the air to a current of less potential and greater amperage. This can be put to work and the long-delayed realization of Franklin's plan of harnessing the electricity of the air be consummated. It may not be a profitable investment from the commercial standpoint, but no one can say what this tapping of the aerial reservoir may lead to. Determining the nature and origin of the aurora will be as great a scientific achievement as utilizing the energy of Niagara Falls.

CHEMISTRY

The Great Problems of Chemistry

By ALFRED RUSSEL WALLACE

THE science of modern chemistry has been created during the present century, but its phenomena and laws are so complex that it presents only a few of those great discoveries which are the starting-points for new developments, and which can at the same time be popularly described. The most important of all—that which constitutes the very foundation of chemistry as a science—is the law of chemical combination in multiple proportions, together with the atomic theory which serves to explain it.

The fact of chemical combination in definite proportions was suspected by some of the older chemists, but Dalton, in the early years of this century, was the first to establish it firmly as a general principle, and to explain it by means of a comparatively simply theory. To illustrate by examples, it is found that the two gases, nitrogen and oxygen, combine to form a variety of compounds, such as nitrous oxide or "laughing gas," nitric oxide, and several others. Nitrous oxide, or in chemical language, nitrogen monoxide, consists of 28 parts by weight of nitrogen to 16 of oxygen, and all the other compounds of the same gases consist of two, three, four, or five times as much oxygen to the same quantity of nitrogen. Water consists of 16 parts of oxygen to 2 of hydrogen, and there is another compound in which 32 parts of oxygen combine with the same weight of hydrogen, forming hydrogen-dioxide or oxygenated water. This law applies to every chemical compound yet discovered, and as every element has a minimum propor-

tionate weight, which can combine with any other element, these are called the atomic or combining weights of the elements. As the weight of the hydrogen in all its combinations is much less than the weight of the element it combines with, this gas is taken as the unit of measurement of atomic weights. Nitrogen is thus found to have an atomic weight of 14, oxygen 16, and chlorine 35. These are all gases; but many solids have much lower atomic weights, carbon being 12, and the rare metal beryllium only 9. Of other metals, that of aluminium is 27, copper 63, iron 56, silver 107, tin 117, and gold 196. There is thus no constant relation between atomic weights and specific gravities. Tin is a little lighter than iron, but has nearly double its atomic weight; gold has a high atomic weight, but bismuth has a higher still, although only half its specific gravity.

These facts are elucidated, and to some extent explained, by the atomic theory of Dalton. He supposed each element to consist of atoms, an atom being the smallest portion that has the properties of the element, and the atom of each element has a different weight. Hence, when one element combines with another, the proportions must be either those represented by the atomic weights, or some multiple of those weights, since the atoms are assumed to be indivisible. This will be made clearer by another example. The atomic weights of nitrogen and oxygen are as 14 to 16, and these elements combine in five different proportions, as shown by the following, each letter representing an atom of the element of which it is the initial letter.

		Chemical Symbol.
N N O	= Nitrogen monoxide	N_2O
N N O O	= Nitrogen dioxide	N_2O_2
N N O O O	= Nitrogen trioxide	O_2N_3
N N O O O O	= Nitrogen tetroxide	N_2O_4
N N O O O O O	= Nitrogen pentoxide	N_2O_5

The atomic or combining weights of all the elements having been carefully determined by numerous experiments, a beautiful system of chemical symbols has been formed which greatly facilitates the study of the innumerable complex substances that have to be investigated. Each element is indicated either

by one or two letters, being the initial letter, or some two characteristic letters, of its chemical name, so that nearly seventy elements are thus clearly defined. But these symbols represent not only the element, but a definite proportional weight—the atomic weight. Thus H means a unit weight of hydrogen; C means 12 times that weight of carbon; Fe (ferrum) means 56 times that weight of iron. Hence the symbol for any compound substance tells us in the most compact form possible, not only the elements of which it is composed, but the exact proportions in which these elements are combined. Thus C_2H_6O is the chemical symbol for pure alcohol, showing that it is a compound of two atoms of carbon, six of hydrogen, and one of oxygen. Looking now at a table of atomic weights, we find that this gives us 24 carbon, 6 hydrogen, and 16 oxygen in each 46 parts of alcohol. By means of these symbols and the accurate determination of atomic weights, all the complex combinations and decompositions that occur during the investigations of the chemist can be represented in a kind of chemical algebra, and the peculiar formulæ thus obtained often suggest further experiments leading to new discoveries.

Almost at the same time that Dalton was working at his atomic theory, Davy (afterward Sir Humphrey Davy) made the remarkable discovery of two new elements by decomposing soda and potash by means of an electric current, resulting in the production of the metals sodium and potassium. This placed in the hands of chemists a powerful agent which led to the discovery of other elements, though in this respect it has been surpassed by spectrum analysis, which is equally effective in the domains of chemistry and astronomy.

Among the more interesting discoveries of modern chemistry are the methods of liquefying the various gases, and even solidifying many of them; while by means of the intense heat of the electric furnace all the solid elements can be melted and many vaporized, leading to the conclusion that all matter can exist in the three states—solid, liquid, and gaseous—according to the degree of heat to which it is exposed.

The highly complex constitution of various organic products—albumin, fat, gums, resins, acids, oils, ethers, etc.—is the

subject of organic chemistry, the study of which has led to some of the most popularly interesting discoveries. Coal-tar has furnished us with a wonderful series of coloring matters, such as the aniline and other dyes, while from the same material are produced benzol, carbolic acid, naphtha, creosote, artificial quinine, and saccharine, a substitute for sugar. The new explosives, such as dynamite and nitro-glycerine, are produced from animal or vegetable fatty matters; while some of the greatest triumphs of the modern chemist are the artificial production of natural substances, which were long supposed to be due to organic processes alone. Such are the dye indigo, citric acid, urea, and some others.

The most recent great advance in the philosophy of chemistry is exhibited in the views of the Russian chemist, Mendeleef, as to the natural arrangement of the elements, with certain deductions from it. The whole of the best-known elements form eight groups, placed in vertical columns, depending on certain similarities in their powers of chemical combination. These are further arranged in twelve horizontal series, in which the atomic weights are most nearly alike, while increasing regularly from the first to the eighth group. In the table thus formed there are certain gaps in the regular order of increased atomic weights, as if some elements were wanting, while in other cases the place of an element due to its atomic weight did not accord with that dependent on its chemical properties. But the general symmetry of the whole arrangement was such that Mendeleef predicted the future discovery of elements to fill the gaps, and named the chemical and physical properties of these unknown elements. In a few years three new elements were discovered—gallium, scandium, and germanium—and they precisely filled up three of the gaps in the system. Further research as to the atomic weights of the elements that did not fit into the scheme showed that errors had been made, that of uranium being much too low, while in the cases of gold, tellurium, and titanium it was too great. The remarkable success of these predictions—a success always considered the best proof of the truth of a theory—renders it almost certain that the true relations of the elements have now been approximately

ascertained, while it strengthens the belief of those who think that what we term elements are not really so, but that their differences depend on special modes of aggregation of a few simple atoms, whose cohesion is so strong that we are not yet, and perhaps never shall be, able to overcome it.

It is therefore by no means impossible, perhaps not even improbable, that methods will be discovered of either breaking up some of the elements and producing new elements which are common to two or more of them, or of solving the problem which occupied the alchemists of the Middle Ages—the transmutation of some of the inferior metals into gold. Within the last few months a well-known American chemist declared that he has solved the problem of producing gold out of silver at a comparatively small cost, and that when he had made a few millions by his process he would make it known. A few years ago this claim would have been scouted as that of a dreamer, but at the present day it is really less unexpected than was the discovery of the marvelous powers of what are termed the Röntgen rays.

It will thus be seen that chemistry, as a science, has not furnished discoveries of such a startling nature as those in the domain of physics. But this is largely due to the fact that we have already, in our earlier chapters, dealt with the more popular and industrial aspects of chemical inventions. Gas illumination, petroleum oil-lamps, lucifer matches, and all the wonders of photography are essentially applications of chemistry; and the last of these, in its marvelous results, both in the arts and in its various applications to astronomical research, is not surpassed by the achievements of any other department of science.

CHEMISTRY

Ancient and Mediæval Chemistry

By M. P. E. BERTHELOT

CHEMISTRY is a modern science, constituted hardly a century ago; but its theoretical problems were discussed and its practices put in operation during all the Middle Ages. The nations of antiquity were already acquainted with them, and their origin is lost in the night of primitive religions and prehistoric civilizations. I have described elsewhere the first rational attempts to explain the chemical transformations of matter, and purpose now to speak of the chemical industries of the ancient world, and their transmission to the Latins of the Middle Ages. The story is of interest as showing how the cultivation of the sciences has been perpetuated in the material line by the necessities of their adaptations, through the catastrophes of invasions and the ruin of civilization. Only the total extermination of populations, such as was at times practiced by the Mongols and the Tartars, could completely destroy this cultivation. But such horrors as those perpetrated by Tamerlane have been of rare occurrence.

From the most remote times man has applied chemical operations to his necessities, performing them for metallurgy, ceramics, dyeing, painting, the preservation of food, medicine, and the art of war. While gold and sometimes silver and copper existed in the native state, and required only mechanical preparation, lead, tin, iron, and often copper and silver, had to be extracted from their usual minerals by very complicated artifices. The production of alloys necessary for the fabrication of arms, money, and jewels is also an essentially chemical art.

The study of the alloys used in goldsmiths' work gave rise to the prejudices and frauds of alchemy, as is proved by the testimony of an Egyptian papyrus preserved in the Leyden Museum, and of the writings of the Grecian alchemists.

The art of preparing cement, pottery, and glass, likewise, depends on chemical operations. The workmen who dyed cloths, clothing, and tapestries in purple or other colors, an industry practiced first in Egypt and Syria and then in all the Grecian, Roman, and Persian world, not to speak of the extreme East, employed highly developed chemical manipulations; and the cloths found on the mummies and in the sarcophagi attest their perfection. Pliny and Vitruvius describe in detail the production of colors, such as cinnabar or vermilion, minium, red chalk, indigo, black, green, and blue colors, vegetable as well as mineral, performed by painters. The chemistry of alimentation, fruitful in resources and in frauds, was next practiced. The art was known of accomplishing at will those delicate fermentations which produce bread, wine, and beer, and which modify a large number of foods; also of falsifying wine by the addition of plaster and other ingredients. The art of healing, seeking everywhere for resources against diseases, had learned to transform and fabricate a large number of mineral and vegetable products, such as sugar of poppy, extracts of nightshade, oxide of copper, verdigris, litharge, white lead, the sulphurets of arsenic and arsenious acid; remedies and poisons were composed at the same time, for different purposes, by doctors and magicians. The manufacture of arms and of inflammatory substances—petroleum, sulphur, resins, and bitumens—had already, anciently as well as in our own time, drawn upon the talents of inventors and given rise to formidable applications, especially in the arts of sieges and marine battles, previous to the invention of the Greek fire, which was in its turn the precursor of gunpowder and of our terrible explosive matters.

This rapid review shows how far advanced in the knowledge of chemical industries the Roman world was at the moment when it went to pieces under the blows of the barbarians. But the ruin of the ancient organization came about by degrees:

while high scientific study, hardly accessible to coarse minds, ceased to be encouraged, and was gradually abandoned; while the Greek philosophers, knocked about between the religious persecution of the Byzantine emperors and the indifferent disdain of the Persian sovereigns, no longer trained pupils; while the great names of Grecian physics, mathematics, and alchemy hardly passed the time of Justinian, it is still certain that the necessity of professions indispensable to human life, or sought out by sovereigns and priests, could maintain and did maintain effectively most of the chemical industries.

Proofs of various kinds can be brought up in support of these reasonings. Some are drawn from the examination of the monuments, arms, potters' and glass ware, cloths, gems and jewels, and art objects of every kind which have come down to us. Such examination furnishes, in fact, incontestable results, provided the dates of the objects are certain, and they have not suffered restoration. Respecting the date, we cannot exercise too much prudence and distrust, whether we are examining buildings or objects in museums. The accounts and descriptions by contemporary historians furnish other data, but less precise, for it is better to have the object in hand than the description. They have the advantage, however, of giving us indications independent of the ulterior progress of the industry. We have a still surer and more exact class of data than the chronicles in the technical treatises and works concerning arts and trades which have come down to us, whenever those treatises have an ascertained date, even were it only the date of their copies. This source of facts is already known as to antiquity. It is not wanting as to the Middle Ages, although it seems to have escaped till now the erudite persons who have written the history of science, and it permits us to reconstitute that under a new form and with a new precision. By the aid of those documents I shall attempt to show, concerning myself especially with chemical industries, what knowledge, practical or theoretical, subsisted after the fall of ancient civilization, and how the traditions of the shop maintained those industries, almost without new inventions, but at least at a certain level of perfection.

The history of physical science in antiquity is very imperfectly known to us. There existed then no methodical treatise for the purpose of teaching, such as we have in the principal civilized states. Hence, except as to the medical sciences, we have only insufficient notions respecting the processes employed in the arts and trades of the ancients. The experimental method of the moderns has associated those practices into a body of doctrines, and has shown close relations between them and the theories for which they served as basis and confirmation. This method was almost unknown to the ancients, and was, at best, only a general principle of scientific learning. Their industries had little connection with theories excepting in measures of length, surface, or volume, which were deduced immediately from geometry and in goldsmiths' receipts—the origin of the theories, partly real and partly imaginary, of alchemy.

It has even been asked whether industrial formulas were not formerly preserved by purely oral tradition and carefully held back for the initiated. Some scraps of the traditional lore may have been transcribed into the notes which have been used in the composition of Pliny's Natural History and the works of Vitruvius and Isidore de Seville, not without a considerable mixture of fables and errors. But a more thorough examination of the works that have come down to us from antiquity, a more attentive study of the manuscripts, at first neglected because they did not relate to literary or theological studies or to ordinary historical questions, permits the affirmation that they were not so. We are all the time discovering new and considerable documents which show that the processes of the ancient industrials were then, as now, inscribed in workmen's note-books or manuals intended for the use of the tradespeople, and that they were transmitted from hand to hand from the most remote times of ancient Egypt and Alexandrine Egypt, to those of the Roman Empire and the Middle Ages. The discovery of these note-books offers all the more interest because the use of the precious metals with civilized peoples goes back to the highest antiquity; the technic of the ancient goldsmiths and jewelers is not revealed to us all at once except

by the examination of the objects that have come down to us. The earliest precise and detailed texts describing their processes are contained in an Egpytian papyrus found at Thebes, and now in the museum at Leyden.

This papyrus is in the Greek language and dates from the third century of the Christian era. In my translation of it, comparing parts of it with phrases in the works of Pliny and Vitruvius on the same subjects and with Greek alchemistic works of the fourth and fifth centuries, I have reconstituted a whole science, ancient alchemy, till now misunderstood and uncomprehended, because it was founded on a mixture of real facts, profound views on the unity of matter, and chimerical religious fancies. These practices and theories had a still larger bearing than the working of metals. The industries of the precious metals were, in fact, associated at that epoch with those of the dyeing of cloths, the coloring of glasses, and the imitation of precious stones, all guided by the same tinctorial ideas and executed by the same operators.

Thus alchemy and the chimerical hope of making gold were derived from the goldsmiths' artifices for coloring metals. The pretended processes of transmutation which were current during the Middle Ages were in their origin only tricks for preparing alloys of inferior standard—that is, for imitating and falsifying the precious metals. But, by an almost invincible attraction the operators addicted to these practices did not hesitate to imagine that one could pass from the imitation of gold to its effective formation—especially if he had the aid of the supernatural powers, invoked by magical formulas.

At any rate, it was not known till now how these practices and theories passed from Egypt, where they were flourishing toward the end of the Roman Empire, into the West, where we find them in full development from the thirteenth and fourteenth centuries in the writings of the Latin alchemists and in the laboratories of the goldsmiths, dyers, and makers of colored glass. Their renaissance was generally attributed to translations of Arabian works made at that epoch. But, without assuming to deny the part played by the Arabian books in the renaissance of the arts and sciences in the West, in the period

of the Crusades, it is no less certain that a continuous tradition subsisted in the professional recollections of the arts and trades from the Roman Empire till the Carlovingian period, and later —a tradition of chemical manipulations and scientific and mystical ideas. In fact, in pursuing my studies of the history of science, I have met, in the examination of the Latin works of the Middle Ages, certain technical manuals which were related most directly with the metallurgical treatises of the Greco-Egyptian alchemists and goldsmiths. I purpose to demonstrate here this correlation, which nobody has till now pointed out.

It is known that the recipes of therapeutics and *materia medica* have been preserved in a parallel way by practice, which has never ceased, in the Receptaries and other Latin treatises; these treatises, translated from the Greek during the period of the Roman Empire, and compiled in the first and second centuries, passed from hand to hand, and were copied frequently during the earlier portions of the Middle Ages. The transmission of the military arts and of fire-producing formulas, particularly, was carried on from the Greeks and Romans through the barbarous ages. In short, the necessity of the applications has always caused the subsistence of a certain experimental tradition of the arts of ancient civilization.

The oldest known technical treatises in Latin of the Middle Ages on subjects in chemistry are the "Formulas for Dyeing" (*Compositiones ad tingendo*), of which we have a manuscript written toward the end of the eighth century, and the "Key to Painting" (*Mappæ clavicula*), the oldest manuscript of which is of the tenth century. The "Formulas for Dyeing" is not a methodical work, but a book of receipts and documents collected by a dyer for use in his art and intended to furnish him with working processes and information concerning the origin of his prime materials. It concerns such subjects as the coloring or dyeing of artificial stones for mosaic work; gliding and silvering and polishing them; making of colored glass in green, milky white, various shades of red, purple, yellow—the colors being both deep and superficial, and often brought out by the aid of simple varnishes; coloring of skins in purple, green, yellow, and various reds; dyeing of woods, bones, and horns;

notices of minerals, metals, and earths used in goldsmiths' work and painting. Curious ideas are set forth on the function of the sun and of heat, peculiar to certain warm earths in the production of minerals endowed with corresponding virtues; while a cold earth produces minerals of weak quality. This reminds us of the theories of Aristotle on dry exhalation as opposed to moist exhalation in the generation of minerals—theories that made an important figure in the Middle Ages. The author distinguishes a feminine and light lead mineral as against a masculine and heavy mineral; a distinction like that mentioned by Pliny between male and female antimony, the male and female blue of Theophrastus, and many others. Minerals were continually likened in the chemistry of the Middle Ages to living beings.

In this work we read, likewise, of articles developed in certain operations, such as the extraction of mercury, lead, the roasting of sulphur, preparations of white lead and vinegar, of verdigris with vinegar and copper—already described by Theophrastus and Dioscorides—of cadmies, impure oxides of lead and zinc, of burned copper (*æs ustum*), of litharge, of orpiment, of artificial cinnabar, etc. The writer mentions a few alloys, such as bronze, white copper, and gold-colored copper—a subject often treated of by the Greek alchemists, who passed from it to the idea of transmutation. The name of bronze (*brundisium*) appears for the first time. While its origin has been the subject of controversy among philologists, the accompanying facts given in the text show that bronze was in the beginning an alloy made at Brundisium for the manufacture of the mirrors of which Pliny speaks. The preparation of parchment and of varnish, the fabrication of vegetable colors for the use of painters and illuminators, and their employment on walls, wood, canvas, etc., in encaustic or with isinglass, are the subjects of separate articles.

A group of formulas for gilding follow: gilding of glass, wood, skins, clothing, lead, tin, and iron; and the preparation of golden wires, processes for writing in golden letters (chrysography) on parchment, paper, glass, or marble. Then come silver foil, tin foil, and processes for reducing gold and silver to

powder, in which mercury and verdigris were employed—the powder obtained by amalgamation being used in processes for silvering and gilding. The process has played its part in political economy; for it has been used to assist the passage of gold and silver from one country to another, in spite of the prohibition of the exportation of the precious metals.

The author goes on to say: "We have described everything relative to tinctures and decorations; we have spoken of the substances which are employed in them—stones, minerals, salts, and herbs; we have shown where they are found; whence are got resins, oleoresins, and earths; what are sulphur, black water, salt waters, glue, and all the products of wild and cultivated plants, domestic and marine; beeswax, axunge, all fresh and acid waters; among woods, the pine, fir, juniper, and cypress, . . . acorns and figs. Extracts are made of all these things with a water made of fermented urine and vinegar, mixed with rain-water."

These enumerations and descriptions mark the nature of the knowledge sought by the writer, and preserve the trace of ancient treatises on drugs and medicines, similar to those of Dioscorides, but more especially devoted to industry. Unfortunately, we have here hardly anything else than titles and summary indications, such as would figure in a dyer's scrap-book, placing, one after another, indications drawn from different authors. Many of the specific names found in the treatise are wanting in the most complete dictionaries. The terms salt, fresh, and acid waters, water formed of fermented urine and vinegar, deserve special notice because they point to the beginning of chemistry by moist processes. They figured in Pliny and the ancient authors, to the same purposes. The liquids are always natural ones or the results of the mixture of such, before or after spontaneous combustion. There is no mention of the active liquids obtained by distillation, which were called divine or sulphurous waters, and held an important place with the Greco-Egyptian chemists, and became the origin of our acids, alkalies, and other agents; they had not yet entered into industrial use, and are seldom met with previous to the fourteenth century.

The group of recipes transmitted by the formulas for dyeing, passed into a more extended collection called the "Key to Painting," of which exist a manuscript of the tenth century in the library of Schlestadt and one of the twelfth century, of which an edition was published in 1847 by Mr. Way. The former manuscript is free from all Arabian influence, which has caused the interpolation of five additional articles in the second one. The work contains a treatise on the precious metals comprising now a hundred articles—about half of the original work, the other half having been lost—and a treatise on recipes for dyeing, representing principally those in the Formulas; together with sixteen articles on military ballistics and fireworks, forming a special group; articles on the hydrostatic balance and the densities of the metals; and industrial and magic recipes, added at the end of the book.

The treatise on the precious metals is of great interest because of the striking analogies it presents with the Leyden Egyptian papyrus found at Thebes, and with other ancient works. Many of the recipes are literally translated from these ancient works; an identity proving indisputably the continuous preservation of alchemic practices, including transmutation, from Egypt down to the artisans of the Latin West. The theories proper, on the other hand, did not reappear in the West till toward the end of the twelfth century, after they had passed through the Syrians and the Arabs. But the knowledge of the processes themselves was never lost. This fact is demonstrated by the study of the alloys intended to imitate and falsify gold; for coloring (copper) gold-color; for fabricating gold; for making test gold; for rendering gold heavier; and for doubling gold. The recipes are filled with Greek words that betray their origin.

The object for the most part is simply to make base gold, as, for instance, by preparing an alloy of gold and silver, colored with copper. The goldsmith, however, tried to make this pass for pure gold. Then manufactures of complex alloys which were made to pass for pure gold were made easier by the intervention of mercury and sulphurets of arsenic, the use of which goes back to the earliest times of the Roman Empire. Thus

Pliny relates in a few lines an experiment performed by order of Caligula for fabricating gold with sulphuret of arsenic (or orpiment). There was thus a whole special chemistry, now abandoned, which was conspicuous in the practices and pretensions of the alchemists. A patent has been obtained in our own times for an alloy of copper and antimony, containing six hundredths of the latter metal, which presents most of the apparent properties of gold and is worked in the same manner. Alchemic gold belonged to a family of similar alloys. Those who made it fancied besides that some agents played the part of ferments to multiply gold and silver. Before deceiving other people they deluded themselves. Sometimes the artisan was satisfied to use a cement or superficial action, painting the surface of silver in gold or the surface of copper in silver, without modifying the metals in their thickness. This is what goldsmiths still call giving color. They would even do no more than apply to the surface of the metal a gold-colored varnish, prepared with the bile of animals or with certain resins, as is still done. From these colorings the operator, led by a mystic analogy, passed to the idea of transmutation, in the false Democritus and in the Key to Painting. The author of the last work concluded, for example, with the words, "You will thus obtain excellent gold and fit for the test." The author added, further, "Hide this sacred secret, which should be delivered to no one, nor to any prophet." The word prophet betrays the Egyptian origin of the recipe. It refers to the Egyptian priests, who, according to a passage in Clement of Alexandria on the Hermetic books that were borne with great pomp in the processions, were called prophets.

In further proof of the Greco-Egyptian origin of goldsmiths' recipes contained in the "Key to Painting," is the existence in the Latin collection of ten recipes—some of the elaborate ones —which are phrased in precisely the same terms in the Greek papyrus in Leyden; the former text being translated from the latter, even to the detail of certain technical expressions, which are still perpetuated in the goldsmiths' manuals of the present. This does not mean that the text transcribed in the "Key to Painting" was originally translated from the very papyrus that

we possess, which was not found till the nineteenth century at Thebes, Egypt; but the coincidence of the text proves that there existed books of secret goldsmiths' recipes transmitted from hand to hand of the tradesmen, which continued through the Middle Ages, and of which the Key is an example. It was firmly believed in the time of Diocletian that the Egyptians had the secret of enriching themselves by making gold and silver; and in consequence of this belief, after a revolt, the Emperor ordered all their books burned. Nevertheless, as we have seen, the formulas did not disappear.

The title of one of the recipes in the old table, "How to make unbreakable glass," deserves to be dwelt upon, on account of the legends and traditions that are associated with it, and which have been perpetuated down to our own time. Unbreakable glass appears to have been really discovered under Tiberius, and gave rise to a legend according to which its properties were amplified and it was made malleable. Tiberius, according to Pliny, caused the factory to be destroyed, for fear that the invention would diminish the value of gold and silver. "If it was known," wrote Petronius, "gold would become as cheap as mud." According to Dion Cassius, Tiberius slew the author. Petronius, who is repeated by other authors, says that he was decapitated, and adds that "if vessels of glass were not fragile they would be preferable to vessels of gold and silver."

These stories relate evidently to the same historical fact, reported by contemporaries, but disfigured by legend; the invention was probably suppressed for fear of its economical consequences. It is very curious to find it mentioned in the goldsmiths' recipes of the Middle Ages, as if the secret tradition had been preserved in the shops. Some of them claimed that glass could be made malleable and ductile and changed into a metal. A process for making glass that will not break has been discovered in our own times, and is announced unequivocally and in definite shape. In truth, malleable glass was not really in question; but even that is not a chimera. Industrial processes for beating and molding glass, based on the plasticity and malleability which it possesses at a temperature near fusion, have been described in late years. An article in the "Key to Paint-

ing" seems to point to a similar process. Real properties, perceived doubtless from antiquity and preserved as shop secrets, gave rise to the legend.

The collection bearing the name of Eraclius or Heraclius is in two parts, of different composition and date. The first part consists of two books in verse, having the character of the writing of the end of the Carlovingian epoch, or of the ninth and tenth centuries. It treats of vegetable colors, of gold leaf, of writing in letters of gold, of gilding, of painting on glass, and of the preparation of precious stones. All the recipes are of ancient origin, a little vague, and without novelty. A book in prose is more compact and precise. It was added later by a continuator, toward the twelfth century, for there is a discussion in it of the coloring of Cordovan leather, and cinnabar, which is red, is called in it azure—a translation of an Arabic word, frequent in the twelfth century, which has given rise to all sorts of misconceptions and confusion with our modern azure blue. It has the stories about malleable glass; and most of the subjects were already treated in the "Key to Painting."

The "Picture of Different Arts" of the monk Theophilus seems to be the work of an author who lived at the end of the eleventh century and beginning of the twelfth. It is more exact and detailed than the work of Eraclius, and is composed of two parts—the first devoted to painting, and the second concerning the making of objects required in worship and the construction of buildings devoted to it. It describes in detail the furnace for melting glass and the manufacture of glass, the making of painted glass and colored earthen vessels, the working of iron, the melting of gold and silver and the working of them, enamel, the fabrication of vessels used in worship—the chalice, monstrance, etc.—organs, bells, cymbals, etc. The facts are curious, for they show that the industry of glass and metals had finally concentrated around the religious edifices. But the chemical technique is the same as that of the other books, though savoring of more modern influences; it brings us directly to the thirteenth and fourteenth centuries, from which period monuments and writings multiply more rapidly down into modern times. The derivation of technical tradi-

tions from antiquity becomes less and less manifest as intermediaries multiply and the arts tend to assume an original character.

The facts I have presented deserve our attention as a whole, in view of the course and renaissance of scientific traditions Sciences begin in fact with practice. The first object is to satisfy the necessities of life and the artistic wants that awaken early in civilizable races. But this same practice at once calls out more general ideas, which appeared first among mankind in a mystic form. With the Egyptians and Babylonians the same persons were at once the priests and the men of science. Thus the chemical industries were first exercised around the temples. The "Book of the Sanctuary," the "Book of Hermes," and the "Book of Kemi," all synonymous denominations with the Greco-Egyptian alchemists, represent the earliest manuals of those industries. It was the Greeks, as in all other scientific branches, who gave these treatises a revision freed from the old hieratic forms, and who tried to draw from them a rational theory, capable in its turn, by a similar application, of pushing the practice forward and of serving as a guide to it. But the chemical science of the Greco-Egyptians never rid itself of the errors relative to transmission—which were sustained by the theory of primal matter—or of the religious and magic formulas formerly associated in the East with every industrial operation. Yet when scientific study proper perished with Roman civilization in the West, the wants of life kept up the imperishable practice of the shops with the progress required in the time of the Greeks, and the chemical arts subsisted; while the theories, too subtile or too strong for the minds of the time, tended to disappear, or rather to return toward the ancient superstitions. In the "Key to Painting," as in the Egyptian papyrus and the texts of Zosimus, are mentions of prayers to be recited during the operations; and in this way alchemy remained intimately connected with magic in the Middle Ages as well as in antiquity.

During the Latin Middle Ages, toward the thirteenth century, when civilization began to revive, in the midst of a new organization, our races took up anew the taste for general ideas,

and these, in the sphere of chemistry, were sustained by practices, or rather they obtained their support in the permanent problems raised by them. Thus the alchemistic theories were suddenly revived, with new vigor and development, and their progressive evolution, while improving industry, gradually eliminated the superstitions of former times. Thus was finally constituted our modern chemistry, a rational science, established on purely experimental bases. The science was therefore born in its beginning of industrial practices; it kept course with their development during the reign of ancient civilization; when science went down with civilization practice survived and furnished science a solid ground on which it was able to achieve a new development when the times and the minds had become favorable. The historical connection of science and practice in the history of civilizations is therefore manifest. There is in it a general law of the development of the human mind.

CHEMISTRY

Chemical History of a Candle

(*Selection*)

By MICHAEL FARADAY

WHAT is all this process going on within us which we cannot do without, either day or night, which is so provided for by the Author of all things, that He has arranged that it shall be independent of all will? If we restrain our respiration, as we can to a certain extent, we should destroy ourselves. When we are asleep, the organs of respiration, and the parts that are associated with them, still go on with their action, so necessary is this process of respiration to us, this contact of air with the lungs. I must tell you, in the briefest possible manner, what this process is. We consume food: the food goes through that strange set of vessels and organs within us, and is brought into various parts of the system, into the digestive parts especially; and alternately the portion which is so changed is carried through our lungs by one set of vessels, while the air that we inhale and exhale is drawn into and thrown out of the lungs by another set of vessels, so that the air and the food come close together, separated only by an exceedingly thin surface: the air can thus act upon the blood by this process, producing precisely the same results in kind as we have seen in the case of the candle. The candle combines with parts of the air, forming carbonic acid, and evolves heat; so in the lungs there is this curious, wonderful change taking place. The air entering, combines with the carbon (not carbon in a free state, but, as in this case, placed ready for action at the moment), and makes carbonic acid, and is so thrown out into the atmos-

phere, and thus this singular result takes place: we may thus look upon the food as fuel. Let me take that piece of sugar, which will serve my purpose. It is a compound of carbon, hydrogen, and oxygen, similar to a candle, as containing the same elements, though not in the same proportion; the proportions in sugar being as shown in this table:

Carbon	72	
Hydrogen	11	99
Oxygen	88	

This is, indeed, a very curious thing, which you can well remember, for the oxygen and hydrogen are in exactly the proportions which form water, so that sugar may be said to be compounded of seventy-two parts of carbon and ninety-nine parts of water; and it is the carbon in the sugar that combines with the oxygen carried in by the air in the process of respiration, so making us like candles; producing these actions, warmth, and far more wonderful results besides, for the sustenance of the system, by a most beautiful and simple process. To make this still more striking, I will take a little sugar; or to hasten the experiment I will use some syrup, which contains about three-fourths sugar and a little water. If I put a little oil of vitriol on it, it takes away the water, and leaves the carbon in a black mass, and before long we shall have a solid mass of charcoal, all of which has come out of sugar. Sugar, as you know, is food, and here we have absolutely a solid lump of carbon where you would not have expected it. And if I make arrangements so as to oxidize the carbon of sugar, we shall have a much more striking result. Here is sugar, and I have here an oxidizer—a quicker one than the atmosphere: and so we shall oxidize this fuel by a process different from respiration in its form,—though not different in its kind. It is the combustion of the carbon by the contact of oxygen which the body has supplied to it. If I set this into action at once, you will see combustion produced. Just what occurs in my lungs—taking in oxygen from another source, namely, the atmosphere—takes place here by a more rapid process.

You will be astonished when I tell you what this curious play of carbon amounts to. A candle will burn some four, five, six, or seven hours. What a wonderful change of carbon must take place under these circumstances of combustion or respiration! A man in twenty-four hours converts as much as seven ounces of carbon into carbonic acid; a milch cow will convert seventy ounces, and a horse seventy-nine ounces, solely by the act of respiration. That is, the horse in twenty-four hours burns seventy-nine ounces of charcoal, or carbon, in his organs of respiration, to supply his natural warmth in that time. All the warm-blooded animals get their warmth in this way, by the conversion of carbon, not in a free state, but in a state of combination. And what an extraordinary notion this gives us of the alterations going on in our atmosphere. As much as 5,000,000 pounds, or five hundred and forty-eight tons, of carbonic acid is formed by respiration in London alone in twenty-four hours. And where does all this go? Up in the air. If the carbon had been like the lead which I showed you, or the iron, which in burning produces a solid substance, what would happen? Combustion could not go on. As charcoal burns it becomes a vapor, and passes off into the atmosphere, which is the great vehicle, the great carrier for conveying it away to other places. Then what becomes of it? Wonderful is it to find that the change produced by respiration, which seems so injurious to us (for we cannot breathe air twice over), is the very life and support of plants and vegetables that grow upon the surface of the earth. It is the same also under the surface, in the great bodies of water; for fishes and other animals respire upon the same principle, though not exactly by contact with the open air.

CHEMISTRY

Liquid Air

By IRA REMSEN *

WATER, the substance most familiar to us, is known in the liquid, in the solid, and in the gaseous state. Everybody knows that by heating the solid it passes into the liquid state, and that by heating the liquid it passes into the form of gas or vapor. So also everybody knows that when the vapor of water is cooled it is liquefied, and that by cooling liquid water sufficiently it becomes solid or turns to ice. In the same way many of the substances that are known to us as liquids, such as alcohol and ether, can be converted into the form of gas or vapor by heat. In fact, this is true of most liquids. The temperature at which a solid passes into the liquid state is called its melting point, and the temperature at which a liquid passes into the gaseous state is called its boiling point. The boiling point of water, for example, is 100° C. (212° F.) in the open air. But the boiling point varies with the pressure exerted upon the surface. The pressure that we ordinarily have to deal with is that of the atmosphere. If the pressure is increased the boiling point is raised, and if the pressure is decreased the boiling point is lowered. In dealing, then, with the conversion of a gas into a liquid, or that of a liquid into a gas, both the temperature and the pressure have to be considered.

Just as water is most familiar to us in the liquid form, so there are substances that are most familiar to us in the gaseous form. In fact, the only gaseous substances that can be said to

* President of Johns Hopkins University.

be familiar to everybody are the gases contained in the air. The principal constituents of the air are nitrogen and oxygen, which form respectively about four-fifths and one-fifth of its bulk. Besides these gases, however, the air contains water vapor, carbonic-acid gas, ammonia, argon in small quantities, and many other substances in still smaller quantities. For the purposes of this article it is only necessary to have in mind the nitrogen, oxygen, water vapor, and carbonic acid. Of these, the water vapor is easily converted into liquid, as, for example, in the formation of rain, while the other constituents are liquefied with difficulty. The name "liquid air" is applied to the substance that is obtained by converting the air as a whole into a liquid; but in this process the water and the carbonic acid become solid and can be filtered from the liquid so that the latter consists almost wholly of oxygen and nitrogen. A few years ago this liquid was obtainable in only very small quantities. To-day, thanks especially to the efforts of Mr. Charles E. Tripler, of New York, it can be produced in any desired quantity, and at moderate cost. In consequence of this, it has come to be talked about in a familiar way, and many persons have had the privilege of seeing and feeling it, and of learning something about its wonderful properties. The object of this article is to explain the method employed in the production of liquid air, to give an account of some of its properties, and to indicate some of the uses to which it may possibly be put.

In the older text-books of physics and of chemistry certain gases were classed as "permanent," under the impression that these could not be liquefied, and this impression was based upon the fact that all efforts to liquefy them had failed. A brief account of these efforts will be helpful.

Among the so-called permanent gases was chlorine. An English chemist, Northmore, first succeeded, early in this century, in liquefying chlorine. His work was, however, lost sight of, and in 1823 Faraday at the Royal Institution showed independently that this transformation of gaseous chlorine into the liquid can be effected comparatively easily. The method used by him is this: When chlorine gas is passed into cold water it forms with the water a solid product known as chlorine hydrate.

If kept well cooled this hydrate can be dried. If then its temperature is raised even to the ordinary temperature of the room, the solid hydrate is decomposed into liquid water and gaseous chlorine. Faraday put some of the solid hydrate into a stout glass tube sealed at one end and bent at the middle. The other end of the tube was then closed. The tube was then suspended so that the two ends were turned downward. On gently warming the end in which was the solid hydrate this was decomposed into chlorine and water. But the gas given off would under ordinary conditions have occupied a much larger space than the solid hydrate. Being prevented from expanding by the tube in which it was inclosed, it was under very considerable pressure. The end of the tube that was not warmed was cooled, and in this end, in consequence of the pressure and the comparatively low temperature, chlorine, which is gaseous under the ordinary pressure of the air, appeared as a liquid. The general method made use of by Faraday in this classical experiment is that which is always made use of for the purpose of liquefying gases, but for some gases pressure is very much higher and temperatures very much lower are required. Faraday himself succeeded in liquefying all the gases then known except oxygen, hydrogen, nitrogen, nitric oxide, and marsh gas. He subjected oxygen to a pressure of about one thousand pounds to the square inch, or nearly seventy atmospheres, but it showed no signs of liquefaction. Later experimenters increased the pressure to 4,000 pounds to the square inch, with no better results, so that it is not surprising that it came to be held that some gases are permanent.

Within comparatively recent years several gases have been liquefied on the large scale by means of pressure. These are ammonia, carbonic acid, nitrous oxide, and chlorine. Ammonia is used for producing low temperatures, as in breweries and in cold-storage plants and in the manufacture of ice; carbonic acid, for fire extinguishers and for charging beer with the gas; nitrous oxide, for producing anæsthesia; and chlorine in connection with several branches of chemical manufacture. The production of low temperatures by means of liquid ammonia and of liquid carbonic acid will be more fully dealt with further

on, when the principles involved will be briefly presented. It is to be borne in mind that these substances are liquefied by means of pressure alone, at temperatures that are easily reached, so that it appears that by mechanical pressure it is possible to produce low temperatures. In 1869 an important fact was discovered by Andrews. It was that for every gas there is a temperature above which it is impossible to liquefy it by pressure. Thus, if chlorine is at any temperature above 146° C. (294° F.) it cannot be liquefied. This temperature is called the "critical temperature" of chlorine. The pressure to which the gas must be subjected at the "critical temperature" in order that the gas may be liquefied is called the "critical pressure." In the case of chlorine this is 93.5 atmospheres. Now the critical temperature of the gases that were called permanent gases are very low—lower than could be reached by the means at the command of earlier experimenters. The critical temperature of oxygen, for example, is −118.8° C. (−182° F.), while that of nitrogen is −146° C. (−230° F.). The critical pressures are 50.8 and 35 atmospheres respectively. As there is no difficulty in obtaining these pressures, the problem of liquefying oxygen and nitrogen and air resolves itself into finding a method of producing temperatures below the critical temperatures of these gases.

It is well known that a temperature somewhat below the freezing point of water can be produced artificially by mixing ice and salt. The ordinary ice-cream freezer is a familiar application of this method of producing cold. Other freezing mixtures that are sometimes used consist of calcium chloride and snow, that gives the temperature −48° C. (−54.4° F.), and solid carbonic acid and ether, that is capable of lowering the temperature to −100° C. (−148° F.). But even with the latter mixture it is not possible to reach the critical temperature of oxygen or that of nitrogen. How, then, is it possible to reach these extremely low temperatures?

In order to answer this question it will be necessary to take into consideration certain temperature changes that are observed when solids are melted and liquids are boiled, as well as when gases are liquefied and liquids are frozen. When heat is

applied to a mass of ice at its melting point it melts and forms a mass of water having the same temperature. Heat disappears in the operation. It is stored up in the water. This disappearance of heat that accompanies the melting of ice can be shown in a very striking way by mixing a certain weight of ice with the same weight of water that has been heated to 80° C. (176° F.). The ice will melt and all the water obtained will be found to have the temperature of the melting ice—that is, 0° C. (32° F.). The water of 80° C. is thus cooled down to 0° by the melting of the ice. Again, when heat is applied to water its temperature rises until the boiling point is reached. Then it is converted into vapor, but this vapor has the temperature of the boiling water. During the process of boiling there is no rise in the temperature of the water or of the vapor. Heat disappears, therefore, or is used up in the process of vaporization. Similar phenomena are observed whenever a solid is melted or a liquid is boiled. When, however, a gas is liquefied it gives up again the heat that is absorbed by it when it is formed from a liquid; and so also when a liquid solidifies it gives up the heat it absorbs when it is formed from a solid.

But it is not necessary that a gas should be converted into a liquid in order that it should give up heat. Whenever it is compressed it becomes warmer. Some of the heat stored up in it is, as it were, squeezed out of it. Conversely, whenever a gas expands, it takes up heat and, of course, surrounding objects from which the heat is taken become colder. Now, it is a comparatively simple matter to compress air. Every wheelman knows that, and he also knows that the process causes a rise in temperature; at least he knows it if he uses a small hand pump. With large pumps run by steam any desired pressure can be reached. This is simply a question of securing the proper engines, and vessels sufficiently strong to stand the pressure. It has already been pointed out that several gases are now liquefied on the large scale by means of pressure. It is to be noted that low temperatures can be produced by converting certain gases, such as ammonia and carbonic acid, into liquids, and by compressing certain gases, as, for example, air. When liquefied gases are used it is only necessary to allow

them to pass rapidly into the gaseous state, when more or less heat is absorbed. This is the basis for the use of liquid ammonia in the manufacture of ice. A vessel containing the liquid ammonia is placed in another containing water. The inner vessel being opened, the liquid ammonia is rapidly converted into the gas; heat is absorbed from the water; it freezes. When a vessel containing liquid carbonic acid is opened so that the gas that is formed escapes through a small valve, so much heat is absorbed that a part of the liquid carbonic acid is itself frozen. In this case the substance is present in all three states of aggregation—the solid, the liquid, and the gaseous. The use of a mixture of ether and solid carbonic acid as a feezing mixsture has already been referred to. Its value depends, of course, principally upon the fact that solid carbonic acid is liquefied, and the liquid then converted into gas, both of which operations involve absorption of heat.

We are now prepared to understand the important experiments of Cailletet and of Pictet, the results of which were published in 1877. It should be said that they worked independently of each other—Cailletet in Paris and Pictet in Geneva. Pictet liquefied carbonic acid and sulphur dioxide by pressure. The liquid carbonic acid was passed through a tube that was surrounded by liquid sulphur dioxide boiling in a partial vacuum. The liquid carbonic acid thus cooled was then boiled under diminished pressure in a jacket surrounding a tube in which the gas to be liquefied was contained under high pressure. When this gas was allowed to escape from a small opening its temperature was so reduced by the expansion that a part of it was liquefied in the tube and passed off as a liquid. Cailletet worked in essentially the same way, but on a smaller scale. Neither of these experimenters liquefied oxygen or nitrogen on the large scale, but they pointed out the way that must be followed in order that success may be attained. They destroyed the belief in "permanent" gases.

Later experimenters in this field are Wroblewski, Olszewski, and Dewar, who have been interested mainly in the purely scientific side of the problem, while Linde in Germany, Hampson in England, and Tripler in the United States have their minds

on the practical side. Notwithstanding the low temperatures involved in the experiments, a number of heated discussions have been carried on in the scientific journals touching the question of priority. To the unprejudiced observer it appears that all of those named above are entitled to credit. They have all helped the cause along, but just how to apportion the credit no one knows. In a general way, however, some of the results obtained by each in turn should be given. Wroblewski and Olszewski have carried on the work begun by Cailletet and Pictet, and have produced lower temperatures.

In the latest form of apparatus used by Olszewski, liquid ethylene is used as the cooling agent. Its boiling point is $-102°$ C. ($-151.6°$ F.). By causing it to boil rapidly under diminished pressure a temperature below the critical temperature of oxygen can be reached. As early as 1891, Olszewski obtained as much as two hundred cubic centimeters of liquid air by this method. Dewar has also made use of liquid ethylene. This was passed through a spiral copper tube surrounded by solid carbonic acid and ether. It was then passed into a cylinder surrounded by another cylinder containing solid carbonic acid and ether. A spiral copper tube, which runs through the outer cylinder and also through the inner cylinder in which the ethylene was boiling under diminished pressure, carried the air. This was liquefied and then collected in a vacuum vessel below. Later he found that air can be liquefied by using liquid carbonic acid alone as the cooling agent. As he remarks: "With this simple machine, one hundred cubic centimeters of liquid oxygen can readily be obtained, the cooling agent being carbon dioxide, at the temperature of $-79°$. If liquid air has to be made by this apparatus, then the carbonic acid must be kept under exhaustion of about one inch of mercury pressure, so as to begin with a temperature of $-115°$."

The introduction of the vacuum vessel by Dewar has been of great service in all the work on liquefied gases. A vacuum vessel is a double-walled glass vessel. The space between the inner and outer walls of the vessel is exhausted by means of an air pump before it is closed. The vessel is therefore surrounded by a vacuum. As heat is not conducted by a

vacuum, it is possible to keep specimens of liquefied gases in such vessels for a surprisingly long time. Heat enough cannot pass through the vacuum to vaporize the liquid rapidly. The most common form of these vessels is that of a globe. Such a vessel is known as a Dewar globe or bulb.

It has been found that liquid air can be kept very well by putting it in a tin or galvanized iron vessel, which in turn is placed in a larger one, and then filling the space between the two with felt. Under these conditions vaporization takes place quite slowly, and it is possible to transport the liquid comparatively long distances. It has, for example, been transported from New York to Baltimore and Washington. In one case with which the writer is familiar two cans were taken from Mr. Tripler's laboratory in the morning, delivered at the Johns Hopkins University in the afternoon, and used to illustrate a lecture in the evening. After the lecture there was enough left for certain experiments that were carried on during the rest of the night.

Tripler, Linde, and Hampson have all succeeded in devising forms of apparatus by means of which air can be liquefied without the aid of other cooling agents than the expanding air. In principle the methods employed by these three workers are essentially the same. It appears from the published statements that at the present time Tripler's plant is the most efficient. While a few years ago a half pint or so of liquid air is said to have cost $500, now five gallons can be made for about $20, and probably much less. The general working of Tripler's apparatus is as follows. Given three steam compression pumps. Air is taken from above the roof of the laboratory. In the first pump it is compressed to sixty-five pounds to the square inch. It, of course, becomes heated as it is compressed. In order to cool it down again it is passed through a coil connecting the first and second pumps, which is surrounded by water of the ordinary temperature. This compressed and cooled air is then further compressed in the second pump to four hundred pounds to the square inch. Again it is cooled in the same way as before by means of water which circulates around a coil connecting the second and third pumps. Once

more the air is compressed this time in the third pump, in which it is subjected to a pressure of 2,000 to 2,500 pounds to the square inch; and then this compressed air is brought down to the ordinary temperature in a cooler consisting of a coil similar to those connecting the pumps. The air under this great pressure is now passed through a purifier where it is freed from particles of dust and to a great extent from moisture. From the purifier the air passes into an inner bent tube, about thirty feet in length, at the end of which, the critical point of the apparatus, is situated a needle valve from which the air is allowed to escape. It, of course, expands enormously, and is correspondingly cooled. This very cold air passes into the space between the inner and outer tubes, and finally escapes at a vent at the other end of the bent tube. The result of this is that the compressed air in the inner tube is soon cooled down so far that a considerable part of the air that escapes at the needle valve appears in the liquid form. This collects in the lower part of the jacket, and on opening the stopcock underneath the liquid escapes in a stream the size of one's finger.

In Mr. Tripler's laboratory the liquid is collected in the cans already referred to. Although for the reasons mentioned the evaporation of the liquid is comparatively slow, it is constantly going on, and as the gas formed occupies a very much larger volume under the pressure of the atmosphere than the liquid from which it is formed, it is necessary to leave the cans loosely covered. Otherwise the pressure would increase to such an extent as to burst any but the strongest vessels. One cubic foot of liquid air gives at atmospheric pressure eight hundred cubic feet of gaseous air.

Liquid air obtained as described is a turbid, colorless liquid. The turbidity is due to the presence of solid water and solid carbonic acid. By passing the liquid through a paper filter the solids are removed, and a transparent liquid is thus obtained. This, as already stated, consists mostly of nitrogen and oxygen in the proportion of about four-fifths of the former to one-fifth of the latter. Though it should not be forgotten that this liquid contains argon in small quantity, besides three or four other substances in still smaller quantities, as has recently been

shown by Professor Ramsay, we may disregard everything except the nitrogen and oxygen. Liquid air is a *mixture* of these two substances. They are not chemically combined as hydrogen and oxygen are, for example, in water. This mixture boils at $-191°$ C ($-312°$ F.), which is the temperature of the liquid as it is in the cans. As the nitrogen boils at a lower temperature ($-194°$ C. or 318° F.) than oxygen ($-183°$ C. or 297° F.), more nitrogen is converted into gas in a given time than oxygen, and after a time the liquid that is left is much richer in oxygen than ordinary air. When liquid air is poured upon water, it, being a little lighter than the water, floats, not quietly, to be sure, but in a very troubled way. Soon, however, the liquid sinks to the bottom because the nitrogen, which is the lighter constituent, passes into the gaseous state, and the liquid oxygen which is left is a little heavier than water. The experiment is a very beautiful one. A scientific poet could alone do justice to it. The beauty is enhanced by the fact that while liquid air is colorless, or practically so, liquid oxygen is distinctly blue.

Although liquid air has the temperature $-191°$ C. ($-312°$ F.), one can without danger pass the hand through it rapidly. The sensation is a new one, but it is evanescent. Very serious results would follow if the hand were allowed to remain in the liquid even for a short time. The tissues would be killed. So also, it is possible to pass the hand rapidly through molten lead without injury. In the latter case the moisture on the hand is converted into vapor which forms a protecting cushion between the hand and the hot liquid; while, in the former case, the heat of the hand converts the liquid air immediately surrounding it into gas which prevents the liquid from coming in contact with the hand.

When the liquid is poured out of a vessel in the air it is rapidly converted into gas. The great lowering in the temperature causes a condensation of the moisture of the air in the form of a cloud. The same thing is seen when the cover is removed from a can containing the liquid. Of course, this liquid does not wet things as water does. When, however, as happened in New York, the lecturer deliberately pours a dipperful

of the liquid upon a priceless Worth gown, he may expect to hear expressions of horror from the owner. This experiment passed off most successfully. Every trace of the liquid air was converted into invisible gases before the fleeting agony of the sympathetic audience had passed away.

The effects of very low temperature upon a number of substances have been studied, and some of them can easily be shown. Paraffin, resin, and rubber immersed in liquid air soon become very brittle, and the color of the resin is completely changed. A beefsteak or an onion also becomes brittle, and can be broken into small fragments by the blow of a hammer. A similar effect is produced in the case of some metals. Tin and iron, for example, become brittle, and the tenacity of the iron is greatly increased. A copper wire, however, retains its flexibility. At low temperatures the electric conductivity of all metals is increased. In general, the lower the temperature the greater the conductivity. If a copper wire could by any means be kept cold enough, electrical energy could be transmitted by it with but little loss—perhaps none. Mercury is easily frozen by surrounding it with liquid air, and the solid thus formed is very hard, though if it is cooled down sufficiently it becomes brittle.

Alcohol can be frozen without difficulty by means of liquid air. By the aid of the lowest temperatures hitherto attainable it has only been possible to convert alcohol into a pasty mass. The frozen alcohol is as hard as ice. When alcohol is dropped into liquid air the drops retain the globular form. When taken out on a platinum loop the flame of a Bunsen burner does not set fire to it.

Phosphorescence is greatly increased by cooling substances down to the temperature of liquid air. This has been shown by means of water, milk, paper, eggs, and feathers. An egg and a feather could be distinctly seen in a dark room.

Scarlet iodide of mercury is converted into the yellow variety when it is subjected to the temperature of liquid air. Some other colors are changed under the same circumstances, but not enough is known of this subject to warrant a general statement.

Attention has already been called to the fact that liquid air loses its nitrogen more rapidly than it does its oxygen, and that, after a time, the residue contains a large proportion of oxygen. As combustion is combination with oxygen, combustion or burning takes place more readily in contact with this liquid oxygen than it does in the air. If a lighted match is attached to the end of a steel watch-spring, and this then plunged beneath the surface of liquid air, the spring will soon take fire and burn brilliantly, the sparks flying off for some distance in beautiful coruscations. Hair felt, which does not burn in the air, burns in a flash when soaked with liquid air. Finally, when liquid air is confined in any vessel not capable of sustaining an enormous pressure, say about 10,000 pounds to the square inch, the vaporization goes on until the vessel bursts or the stopper is forced out. It might therefore be used as an explosive without any addition, but its manipulation is not altogether simple.

Now for the inevitable question: Of what use is liquid air likely to be? This is a perfectly proper question, and yet if scientific workers always stopped to ask it and would not work unless they could find a favorable answer, progress would, to say the least, be much slower than it is. Most great practical discoveries have necessarily passed through the plaything stage. Some of the most important discoveries have not even furnished playthings, and have found no practical applications as this expression is commonly understood. But the production of liquid air, while furnishing mankind with a beautiful and instructive plaything, seems likely to find practical applications. We may look for these in four directions, to each of which a short paragraph may be devoted:

First, as a cooling agent. Low temperature is marketable. To be sure, the demand for the extremely low temperature that can be produced by liquid air does not exist to-day, but this concentrated low temperature can be diluted to suit conditions. The only question to be answered in this connection is then, What is the cost of cold produced by liquid air? It is impossible for any one to answer this question at all satisfactorily at present. It can only be said that this is what experimenters

are trying to find out. It appears, however, that they are on the way to cheap liquid air, and that as the processes are improved the price will become lower and lower.

Second, for the construction of motors. There is no doubt that liquid air with its enormous power of expansion can be used as a source of motive power just as compressed air is. In the case of steam it is necessary to heat the water in order to convert it into steam, and to heat the steam to give it the power of expansion. The cost is, in the first instance, that of the fuel. Given a certain amount of heat, and a certain amount of work is obtained. If liquid air is used, the problem is much the same. Engines must be run in order to compress the air which is to be liquefied. Every gallon of liquid air has been produced at the expense of work of some kind. Now, the question arises at once, What proportion of the work that was put in that gallon of liquid air in the course of its production can be got out of it again? It is certain that all of it cannot be got out unless all that we have ever learned about such matters goes for nothing. In dealing with the problem of the application of liquid air as a source of motive power we are therefore doubly handicapped. In the first place, we do not know the cost of the liquid when produced on the large scale; and, in the second place, we do not know the probable efficiency of a liquid-air motor. I say "*we* do not know." Perhaps Mr. Tripler and the others engaged in the experiments on this subject do know approximately. We certainly cannot blame them for not telling us all they know at this stage of the work. It is unfortunate, however, that such a statement as was recently published in a popular magazine should be allowed to gain currency—apparently with the sanction of Mr. Tripler. The statement referred to is to the effect that ten gallons of liquid air have been made by the use of three gallons of liquid air in the engine. If that means that the ten gallons of liquid air are made from air at the ordinary pressure, the statement is in direct conflict with well-established principles. If it means that the ten gallons of liquid air are made from air that has already been partly compressed, we must know how much work has been done before the liquid-air engine began. Leaving

out of consideration the question of cost, it may be pointed out that liquid-air engines would have the advantage of compactness, though they would necessarily be heavy, as they would have to be strong enough to stand the great pressure to which they would be subjected.

The third application of liquid air that has been suggested is in the preparation of an explosive. In fact, an explosive has been made and used for some time in which liquid air is one of the constituents. When the liquid from which a part of the nitrogen has boiled off is mixed with powdered charcoal, the mixture burns with great rapidity and great explosive force. "To make this explosive, Dr. Linde pours the liquid containing about forty or fifty per cent of oxygen on fragments of wood charcoal, two or four cubic millimeters in size. These are kept from scattering under the ebullition of the liquid by mixing them into a sort of sponge with about one-third of their weight of cotton wool." Of course, this explosive must be made at or near the place where it is used. It has been in use in the way of a practical test in a coal mine at Pensberg, near Munich. It is claimed that the results were satisfactory. The chief advantage of the explosive is its cheapness, and the fact that it soon loses its power of exploding.

Finally, the fourth application of liquid air is for the purpose of getting oxygen from the air. This can be accomplished by chemical means, but the chemical method is somewhat expensive. Oxygen has commercial value, and cheap oxygen would be a decided advantage in a number of branches of industry. It will be observed that it is the liquid oxygen that makes possible the preparation of the explosive described in the last paragraph. Oxygen, as such, in the form of gas is of value in Deacon's process for the manufacture of chlorine. In this process air and hydrochloric acid are caused to act upon each other so as to form water and chlorine. The nitrogen takes no part in the act, and it would be an advantage if it could be left out. It is only the oxygen that is wanted. There are many other possible uses for oxygen either in the liquid or in the gaseous form, but these need no mention here.

In conclusion it may safely be said that it is highly probable

that liquid air will be found to be a useful substance, but it is impossible at present to speak with any confidence of the particular uses that will be made of it. As work with it is being carried on energetically in at least three countries, we may confidently expect important developments in the near future.

CHEMISTRY

The Potter's Art

By MARTHA WASHINGTON LEVY

THE progressive steps in the development of almost every art may be traced by examining the art as practiced by peoples of different stages of culture. With pottery, however, this is difficult, since there is only very meager information relating to it among uncivilized peoples, and few facts are recorded concerning the materials used and the methods followed in its production.

Since the art was intimately connected with the securing and preparing of food, it belonged, the world over, among savage tribes of a certain state of culture, to women.

It is probable that the first fire kindled on clay soil baked the clay and suggested to the builder of the fire the possibility of converting a soft and easily molded substance into a hard and permanent article of use. But who the first potter was, or where he worked, is unknown.

Like all arts, pottery was probably the result of a long development. But, after taking root, it flourished in proportion to the advance in culture of the people itself, so that to-day it exists in all stages of development, from the coarse ware of the savage to the fine porcelain of Sèvres.

The earliest examples of pottery belong to the Stone Age and bear all the characteristics of a primitive period. The material of which they are composed is coarse, while the objects themselves, made by hand without the potter's wheel, are crude in form and seem to have been imperfectly hardened in an open fire. The jars are frequently cylindrical in form—though

some are found that are rounded at the base and without feet. Ornamentation is confined to simple, incised lines produced by the impression of the finger-nail, or by a cord wound around the moist clay. Most of the urns of this period are sun-baked.

In the Bronze Age, while most of the pottery was still made by hand, it was wrought more skillfully, and in some instances shows marks of the potter's wheel. The forms, too, were more varied, and circles and figures cut in bronze were introduced as ornaments.

Egypt furnishes the earliest examples of pottery of a more advanced period, the oldest being the sun-dried bricks of which some of the pyramids are made. These occur in the pyramid of Sakkara, dating from the reign of Ouennephes, about 5000 B.C.

That they had the potter's wheel from an early period is shown in the painting on the wall of one of the tombs at Beni-Hassan, dating not far from the pyramid of Shoo-fou. From this it is evident that the art of forming circular objects has hardly been improved in 4000 years: then, as now, the lump of clay was thrown on the wheel to be shaped by the hands or fingers.

The Egyptians produced two varieties of pottery. The first—the ordinary, soft pottery—was used largely for vases, which were made into a variety of forms, and employed chiefly for domestic purposes or cinerary urns. But their highest art was displayed in the use of the enameled pottery, which they were the first to produce. This was usually employed in smaller articles and for inlaying in ornamental work.

From Egypt, the art is supposed to have passed to Nineveh and Babylon, where it was applied to the building of great walls of enameled brick. These colored bricks were formed in a wooden or terra-cotta mold, and many of them were impressed, while still soft, with elaborate cuneiform characters, serving thus to record the victories of the kings.

The finest objects in rude clay were produced by the ancient Greeks, whose most primitive productions, though dating from almost the heroic age, reveal a remarkable power of invention. Most of the vases were made of a fine, sun-dried clay, decorated

with black and coated with glaze. Though some were made by hand, the potter's wheel was used at an early date.

At first no effort at pictorial ornamentation was made, the only attempt at decoration being to cover the clay with interlacing lines. Later, birds, animals, and finally the human figure were introduced.

In Rome, pottery was extensively produced, and consisted largely of tiles, bowls, cinerary urns, and low boat-shaped lamps. The latter, though beautifully embossed, were made of coarse clay which was pressed, while soft, into molds. Later the Romans adopted a black, glazed surface, but in this never attained the perfection achieved by the Greeks. The best-known Roman pottery was the so-called Samian ware, bright red in color and molded in relief on the exterior.

Modern Pottery.

The process by which the present-day pottery is manufactured may be interesting to the reader. The rude clay is ground in a circular pan—the bottom of which is covered with a hard stone—and, after having been run into a large vat, is passed through several sieves of varying fineness. It is then ready to have the moisture eliminated, and for this purpose is pumped under high pressure into clay presses. Finally, after having been cut off into blocks, the clay is ready for use.

In studying the process by which the clay is converted into the various articles with which we are familiar, we visit first the thrower, who, after throwing a ball of clay on the wheel while it is revolving, seizes it and, by manipulation alone, contorts the clay until it has assumed the shape he requires. The wheel itself, while sometimes worked by steam power, can still be seen operated by hand labor as practiced by the potters of antiquity.

After being allowed to dry to a certain consistency, the article formed by the thrower is placed on a circular piece of wood, where all superfluous clay is removed, and it is thus given the proper shape and finish. When handles or spouts are required, they are made in molds and attached to the

articles with water. Flat articles such as plates, and hollow-wares such as soup tureens, are produced by beating out the clay on a suitable bat, smoothing its surface, and then pressing it into plaster of Paris molds. When the clay hardens, it is easily removed, and when quite dry is ready for the oven.

Another mode of producing articles of pottery is by casting. In this case, the plaster molds are filled, not with clay, but with the material, in a "slip" or liquid state. Owing to the suction of the plaster, a coating of clay adheres to the inner surface, and this is filled up until the desired thickness is obtained, when the surplus part is returned to the tub. Many useful articles such as cups, jugs, etc., are produced in this way.

Pottery ware in both the clay and biscuit state has to be fired in "saggars" or pans made of fire-clay. For china firing the ware is embedded in fine-ground flint, but earthenware is placed in clean sand, which prevents the articles from fusing together under the intense heat to which they are subjected.

The biscuit oven, which is the oven in which the ware receives its first fire, is cylindrical in form, with walls made of the hardest fire-brick, built fully two feet thick, and pierced at regular intervals by fire-places which open into the interior. The floor of the kiln is hollow, and over an opening in the center is a column of rings which carry the flame up the center, so that the whole oven is filled with flame.

After the saggars have been carried to the ovens, where they are piled up in tall columns until the entire space is filled, the doorway is bricked up and plastered over, and it is now ready to fire. Meanwhile, a pile of coals has been ignited outside, and the fire is started at all the fire-holes simultaneously.

When the ware is drawn from the oven it is taken to the warehouse, where it is carefully examined to discover any defects that have developed in firing, the defective pieces being rejected, while the others are stored ready for decoration.

Decorations

Printing is one of the most popular modes for decorating pottery. The patterns are engraved upon suitably prepared

A GRECIAN POTTER

From a painting by Paul Thumann.

copper, which the workman, when about to take off a print, places upon a hot stove and covers with a thick dab of color: this he works into every part of the pattern, removes the surplus, and leaves the color only in the incised lines in the copper. He then saturates a piece of prepared tissue-paper with a solution of soft soap and water, places it upon the copper which has been removed quite warm to the press, and after the roller of this has revolved upon it, the engraving is again placed on the stove and the impression removed from the copper. The surplus paper having been cut away, the impression is rubbed upon the piece of ware under great pressure. The paper is then washed away without interfering with the print, and the ware is taken to the "hardening-on" kiln, where it is fired for about nine hours, in order that the thick oil may be burned out of the color, and the ware be thus made ready to receive the glaze.

The materials forming the glaze are fired in a special kiln and afterward mixed with other materials which are ground in water in the mill for about a week. After having been dipped into this glaze, which spreads itself as a thin glassy coating over the whole surface of the article, the latter is taken to the glazing oven, where it is packed in saggars similar to those of the biscuit oven. From there the printed ware is removed to the warehouse, and that requiring further decoration is passed to the enameling department. Here the workers — chiefly women—fill up the printed outline which the ware has already received, with colors, in accordance with the design placed before them.

Another form of decoration found in many china patterns is the addition of a border or coating all over the surface in various colors. This is produced by ground laying, a process consisting of giving the ware a coating of adhesive oil, upon which the color in the form of dust is dabbed upon the surface.

In the gilding department, gold lines are added to the ware, by placing the article on a revolving wheel, which is set in motion by the workman's hand, while he holds the edge of the article. The gold used is the finest that can be obtained, because any alloy would impart to the metal an inferior color.

Finally comes painting on china: the highest class of decoration for pottery.

All articles that are richly decorated with gold upon various colored grounds, or painted upon the glaze, have to be fired in the enamel kiln: an oblong, box-like structure built of fire-bricks and having iron doors. Since no fire whatever penetrates the inside, the structure is very unlike an oven, and is more comparable with a gigantic saggar, with the fire playing around it. The articles are not enclosed in anything, but are arranged upon iron bats supported by short iron props, tier above tier. Then the finished article goes into the wareroom.

EVOLUTION AND NATURE STUDIES

Origin of the Darwinian Theory

By ALFRED RUSSEL WALLACE

WE now approach the subject which, in popular estimation, and perhaps in real importance, may be held to be the great scientific work of the nineteenth century—the establishment of the general theory of evolution, by means of the special theory of the development of the organic world through the struggle for existence and its necessary outcome, Natural Selection. Although in the last century Buffon, Dr. Erasmus Darwin, and the poet Goethe had put forth various hints and suggestions pointing to evolution in the organic world, which they undoubtedly believed to have occurred, no definite statement of the theory had appeared till early in the present century, when La Place explained his views as to the evolution of the stellar universe and of solar and planetary systems in his celebrated Nebular Hypothesis; and about the same time Lamarck published his "Philosophie Zoologique," containing an elaborate exposition of his theory of the progressive development of animals and plants. But this theory gained few converts among naturalists, partly because Lamarck was before his time, and also because the causes he alleged did not seem adequate to produce the wonderful adaptations we everywhere see in nature. During the first half of the present century, owing to the fact that Brazil, South Africa, and Australia then became for the first time accessible to English collectors, the treasures of the whole world of nature were poured in upon us so rapidly that the comparatively limited number of naturalists were fully occupied in describing the new species and endeavoring to discover

true methods of classification. The need of any general theory of how species came into existence was hardly felt; and there was a general impression that the problem was at that time insoluble, and that we must spend at least another century in collecting, describing, and classifying, before we had any chance of dealing successfully with the origin of species. But the subject of evolution was ever present to the more philosophic thinkers, though the great majority of naturalists and men of science held firmly to the dogma that each species of animal and plant was a distinct creation, though how produced was admitted to be both totally unknown and almost, if not quite, unimaginable.

The vague ideas of those who favored evolution were first set forth in systematic form, with much literary skill and scientific knowledge, by the late Robert Chambers in 1844, in his anonymous volume, "Vestiges of the Natural History of Creation." He passed in review the stellar and solar systems, adopted the Nebular Hypothesis, and sketched out the geological history of the earth, with continuous progression from lower to higher forms of life. After describing the peculiarities of the lower plants and animals, dwelling upon those features which seemed to point to a natural mode of production as opposed to an origin by special creation, the author set forth with much caution the doctrine of progressive development resulting from "an impulse which was imparted to the forms of life, advancing them in definite lines, by generation, through grades of organization terminating in the highest plants and animals." The reasonableness of this view was urged through the rest of the work; and it was shown how much better it agreed with the various facts of nature and with the geographical distribution of animals and plants, than the idea of the special creation of each distinct species.

It will be seen, from this brief outline, that there was no attempt whatever to show *how* or *why* the various species of animals and plants acquire their peculiar characters, but merely an argument in favor of the reasonableness of the fact of progressive development, from one species to another, through the ordinary processes of generation. The book was what we

should now call mild in the extreme. It was serious and even religious in tone, and calculated in this respect to disarm the opposition even of the most orthodox theologists; yet it was met with just the same storm of opposition and indignant abuse which assailed Darwin's work fifteen years later. As an illustration of the state of scientific opinion at this time, it may be mentioned that so great a man as Sir John Herschel, at a scientific meeting in London, spoke strongly against the book for its advocacy of so great a scientific heresy as the Theory of Development.

I well remember the excitement caused by the publication of the "Vestiges," and the eagerness and delight with which I read it. Although I saw that it really offered no explanation of the process of change of species, yet the view that the change was effected, not through any unimaginable process, but through the known laws and processes of reproduction, commended itself to me as perfectly satisfactory, and as affording the first step toward a more complete and explanatory theory. It seems now a most amazing thing that even to argue for this first step was accounted a heresy, and was almost universally condemned as being opposed to the teaching of both science and religion!

The book was, however, as great a success as, later on, was Darwin's "Origin of Species." Four editions were issued in the first seven months, and by 1860 it had reached the eleventh edition, and about 24,000 copies had been sold. It is certain that this work did great service in familiarizing the reading-public with the idea of evolution, and thus preparing them for the more complete and efficient theory laid before them by Darwin.

During the fifteen years succeeding the publication of the "Vestiges" many naturalists expressed their belief in the progressive development of organic forms; while in 1852 Herbert Spencer published his essay contrasting the theories of Creation and Development with such skill and logical power as to carry conviction to the minds of all unprejudiced readers; but none of these writers suggested any definite theory of *how* the change of species actually occurred. That was first done in

1858; and in connection with it I may, perhaps, venture to give a few personal details.

Ever since I read the "Vestiges" I had been convinced that development took place by means of the ordinary process of reproduction; but though this was widely admitted, no one had set forth the various kinds of evidence that rendered it almost a certainty. I endeavored to do this in an article written at Sarawak in February, 1855, which was published in the following September in the "Annals of Natural History." Relying mainly on the well-known facts of geographical distribution and geological succession, I deduced from them the law, or generalization, that "Every species has come into existence coincident both in Space and Time with a Pre-existing closely allied Species"; and I showed how many peculiarities in the affinities, the succession, and the distribution of the forms of life were explained by this hypothesis, and that no important facts contradicted it.

Even then, however, I had no conception of *how* or *why* each new form had come into existence with all its beautiful adaptations to its special mode of life; and though the subject was continually being pondered over, no light came to me till three years later (February, 1858), under somewhat peculiar circumstances. I was then living at Ternate in the Moluccas, and was suffering from a rather severe attack of intermittent fever, which prostrated me for several hours every day during the cold and succeeding hot fits. During one of these fits, while again considering the problem of the origin of species, something led me to think of Malthus's Essay on Population (which I had read about ten years before), and the "positive checks"—war, disease, famine, accidents, etc.—which he adduced as keeping all savage populations nearly stationary. It then occurred to me that these checks must also act upon animals, and keep down their numbers; and as they increase so much faster than man does, while their numbers are always very nearly or quite stationary, it was clear that these checks in their case must be far more powerful, since a number equal to the whole increase must be cut off by them every year. While vaguely thinking how this would affect any species, there sud-

denly flashed upon me the idea of *the survival of the fittest*—that the individuals removed by these checks must be, on the whole, *inferior* to those that survived. Then, considering the *variations* continually occurring in every fresh generation of animals or plants, and the changes of climate, of food, of enemies always in progress, the whole method of specific modification became clear to me, and in the two hours of my fit I had thought out the main points of the theory. That same evening I sketched out the draft of a paper; in the two succeeding evenings I wrote it out, and sent it by the next post to Mr. Darwin. I fully expected it would be as new to him as it was to myself, because he had informed me by letter that he was engaged on a work intended to show in what way species and varieties differ from each other, adding, "my work will not fix or settle anything." I was therefore surprised to find that he had really arrived at the very same theory as mine long before (in 1844), had worked it out in considerable detail, and had shown the MSS. to Sir Charles Lyell and Sir Joseph Hooker; and on their recommendation my paper and sufficient extracts from his MSS. work were read at a meeting of the Linnean Society in July of the same year, when the theory of Natural Selection, or survival of the fittest, was first made known to the world. But it received little attention till Darwin's great and epoch-making book appeared at the end of the following year.

We may best attain to some estimate of the greatness and completeness of Darwin's work by considering the vast change in educated public opinion which it rapidly and permanently effected. What that opinion was before it appeared is shown by the fact that neither Lamarck, nor Herbert Spencer, nor the author of the "Vestiges," had been able to make any impression upon it. The very idea of progressive development of species from other species was held to be a "heresy" by such great and liberal-minded men as Sir John Herschel and Sir Charles Lyell; the latter writer declaring, in the earlier editions of his great work, that the facts of geology were "fatal to the theory of progressive development." The whole literary and scientific worlds were violently opposed to all such theories, and

altogether disbelieved in the possibility of establishing them. It had been so long the custom to treat species as special creations, and the mode of their creation as "the mystery of mysteries," that it had come to be considered not only presumptuous, but almost impious, for any individual to profess to have lifted the veil from what was held to be the greatest and most mysterious of Nature's secrets.

But what is the state of educated literary and scientific opinion at the present day? Evolution is now universally accepted as a demonstrated principle, and not one single writer of the slightest eminence, that I am aware of, declares his disbelief in it. This is, of course, partly due to the colossal work of Herbert Spencer; but for one reader of his works there are probably ten of Darwin's, and the establishment of the theory of the "origin of Species by Means of Natural Selection" is wholly Darwin's work. That book, together with those which succeeded it, has so firmly established the doctrine of progressive development of species by the ordinary processes of multiplication and variation that there is now, I believe, scarcely a single living naturalist who doubts it. What was a "great heresy" to Sir John Herschel in 1845, and "the mystery of mysteries" down to the date of Darwin's book, is now the common knowledge of every clever schoolboy, and of every one who reads even the newspapers. The only thing discussed now is, not the fact of evolution—that is admitted—but merely whether or no the causes alleged by Darwin are themselves sufficient to explain evolution of species, or require to be supplemented by other causes, known or unknown. Probably so complete a change of educated opinion, on a question of such vast difficulty and complexity, was never before effected in so short a time. It not only places the name of Darwin on a level with that of Newton, but his work will always be considered as one of the greatest, if not the very greatest, of the scientific achievements of the nineteenth century, rich as that century has been in great discoveries in every department of physical science.

EVOLUTION AND NATURE STUDIES

Bees in the Hive

By ARABELLA B. BUCKLEY

I AM going to ask you to visit with me to-day one of the most wonderful cities in the world. It is a city with no human beings in it, and yet it is densely populated, for such a city may contain from 20,000 to 60,000 inhabitants. In it you will find streets, but no pavements, for the inhabitants walk along the walls of the houses; while in the houses you will see no windows, for each house just fits its owner, and the door is the only opening in it. Though made without hands, these houses are most evenly and regularly built in tiers one above the other; and here and there a few royal palaces, larger and more spacious than the rest, catch the eye conspicuously as they stand out at the corners of the streets.

Some of the ordinary houses are used to live in, while others serve as storehouses where food is laid up in the summer to feed the inhabitants during the winter, when they are not allowed to go outside the walls. Not that the gates are ever shut; that is not necessary, for in this wonderful city each citizen follows the laws; going out when it is time to go out, coming home at proper hours, and staying at home when it is his or her duty. And in the winter, when it is very cold outside, the inhabitants, having no fires, keep themselves warm within the city by clustering together, and never venturing out of doors.

One single queen reigns over the whole of this numerous population, and you might perhaps fancy that, having so many subjects to work for her and wait upon her, she would do noth-

ing but amuse herself. On the contrary, she, too, obeys the laws laid down for her guidance, and never, except on one or two state occasions, goes out of the city, but works as hard as the rest in performing her own royal duties.

From sunrise to sunset, whenever the weather is fine, all is life, activity, and bustle in this busy city. Though the gates are so narrow that two inhabitants can only just pass each other on their way through them, yet thousands go in and out every hour of the day; some bringing in materials to build new houses, others food and provisions to store up for the winter; and while all appears confusion and disorder among this rapidly moving throng, yet in reality each has her own work to do, and perfect order reigns over the whole.

Even if you did not already know from the title of the lecture what city this is that I am describing, you would no doubt guess that it is a bee-hive. For where in the whole world, except indeed upon an ant-hill, can we find so busy, so industrious, or so orderly a community as among the bees? More than a hundred years ago, a blind naturalist, François Huber, set himself to study the habits of these wonderful insects, and with the help of his wife and an intelligent man-servant, managed to learn most of their secrets. Before his time all naturalists had failed in watching bees, because if they put them in hives with glass windows, the bees, not liking the light, closed up the windows with cement before they began to work. But Huber invented a hive which he could open and close at will, putting a glass hive inside it, and by this means he was able to surprise the bees at their work. Thanks to his studies, and to those of other naturalists who have followed in his steps, we now know almost as much about the home of bees as we do about our own; and if we follow out to-day the building of a bee-city and the life of its inhabitants, I think you will acknowledge that they are a wonderful community, and that it is a great compliment to any one to say that he or she is "as busy as a bee."

In order to begin at the beginning of the story, let us suppose that we go into a country garden one fine morning in May when the sun is shining brightly overhead, and that we see hanging from the bough of an old apple-tree a black object

which looks very much like a large plum-pudding. On approaching it, however, we see that it is a large cluster or swarm of bees clinging to each other by their legs; each bee with its two fore-legs clinging to the two hinder-legs of the one above it. In this way as many as 20,000 bees may be clinging together, and yet they hang so freely that a bee, even from quite the center of the swarm, can disengage herself from her neighbors and pass through to the outside of the cluster whenever she wishes.

If these bees were left to themselves, they would find a home after a time in a hollow tree, or under the roof of a house, or in some other cavity, and begin to build their honeycomb there. But as we do not wish to lose their honey we will bring a hive, and, holding it under the swarm, shake the bough gently so that the bees fall into it, and cling to the sides as we turn it over on a piece of clean linen, on the stand where the hive is to be.

And now let us suppose that we are able to watch what is going on in the hive. Before five minutes are over the industrious little insects have begun to disperse and to make arrangements in their new home. A number (perhaps about two thousand) of large, lumbering bees, of a darker color than the rest, will, it is true, wander aimlessly about the hive, and wait for the others to feed them and house them; but these are the drones, or male bees, who never do any work except during one or two days in their whole lives. But the smaller working bees begin to be busy at once. Some fly off in search of honey. Others walk carefully all around the inside of the hive to see whether there are any cracks in it; and if there are, they go off to the horse-chestnut trees, poplars, hollyhocks, or other plants which have sticky buds, and gather a kind of gum called "propolis," with which they cement the cracks and make them air-tight. Others again, cluster round one bee, blacker than the rest and having a longer body and shorter wings; for this is the queen bee, the mother of the hive, and she must be watched and tended.

But the largest number begin to hang in a cluster from the roof just as they did from the bough of the apple-tree. What

are they doing there? Watch for a little while an you will soon see one bee come out from among its companions and settle on the top of the inside of the hive, turning herself round and round, so as to push the other bees back and to make a space in which she can work. Then she will begin to pick at the under part of her body with her fore-legs, and will bring a scale of wax from a curious sort of pocket under her abdomen. Holding this wax in her claws, she will bite it with her hard, pointed upper jaws, which move to and fro sideways like a pair of pincers; then, moistening it with her tongue into a kind of paste, she will draw it out like a ribbon and plaster it on the top of the hive.

After that she will take another piece; for she has eight of these little wax-pockets, and she will go on till they are all exhausted. Then she will fly away out of the hive, leaving a small wax lump on the hive ceiling or on the bar stretched across it; then her place will be taken by another bee, who will go through the same maneuvers. This bee will be followed by another, and another, till a large wall of wax has been built, hanging from the bar of the hive.

Meanwhile, the bees which have been gathering honey out of doors begin to come back laden. But they cannot store their honey, for there are no cells made yet to put it in; neither can they build combs with the rest, for they have no wax in their wax-pockets. So they just go and hang quietly on to the other bees, and there they remain for twenty-four hours, during which time they digest the honey they have gathered, and part of it forms wax and oozes out from the scales under their body. Then they are prepared to join the others at work and plaster wax on to the hive.

And now, as soon as a rough lump of wax is ready, another set of bees come to do its work. These are called the *nursing bees*, because they prepare the cells and feed the young ones. One of these bees, standing on the roof of the hive, begins to force her head into the wax, biting with her jaws and moving her head to and fro. Soon she has made the beginning of a round hollow, and then she passes on to make another, while a second bee takes her place and enlarges the first one. As

many as twenty bees will be employed in this way, one after another, upon each hole before it is large enough for the base of a cell.

Meanwhile another set of nursing bees has been working just in the same way on the other side of the wax, and so a series of hollows are made back to back all over the comb. Then the bees form the walls of the cells, and soon a number of six-sided tubes, about half an inch deep, stand all along each side of the comb ready to receive honey or bee-eggs.

These cells fit closely into each other; even the ends are so shaped that, as they lie back to back, the bottom of one cell fits into the space between the ends of three cells meeting it from the opposite side, while they fit into the spaces round it. Upon this plan the clever little bees fill every atom of space, use the least possible quantity of wax, and make the cells lie so closely together that the whole comb is kept warm when the young bees are in it.

There are some kinds of bees who do not live in hives, but each one builds a home of its own. These bees—such as the upholsterer bee, which digs a hole in the earth and lines it with flowers and leaves, and the mason bee, which builds in walls—do not make six-sided cells, but round ones, for room is no object to them. But nature has gradually taught the little hive-bee to build its cells more and more closely, till they fit perfectly within each other. If you make a number of round holes close together in a soft substance, and then squeeze the substance evenly from all sides, the holes will gradually take a six-sided form, showing that this is the closest shape into which they can be compressed. Although the bee does not know this, yet as she gnaws away every bit of wax that can be spared, she brings the holes into this shape.

As soon as one comb is finished, the bees begin another by the side of it, leaving a narrow lane between, just broad enough for two bees to pass back to back as they crawl along, and so the work goes on till the hive is full of combs.

As soon, however, as a length of about five or six inches of the first comb has been made into cells, the bees which are bringing home honey no longer hang to make it into wax, but

begin to store it in the cells. When the bee goes to fetch her honey she settles on a flower, thrusts into it her small tongue-like proboscis, which is really a lengthened under-lip, and sucks out the drop of honey. This she swallows, passing it down her throat into a honey-bag or first stomach, which lies between her throat and her real stomach, and when she gets back to the hive she can empty this bag and pass the honey back through her mouth again into the honey-cells.

But if you watch bees carefully, especially in the spring time, you will find that they carry off something else besides honey. Early in the morning, when the dew is on the ground, or later in the day, in moist, shady places, you may see a bee rubbing itself against a flower, or biting bags of yellow dust, or pollen. When she has covered herself with this she will brush it off with her feet, and, bringing it to her mouth, she will moisten and roll it into a little ball, and then pass it back from the first pair of legs to the second, and so to the third or hinder pair. Here she will pack it into a little hairy groove, called a "basket," in the joint of one of the hind legs, where you may see it, looking like a swelled joint, as she hovers among the flowers. She often fills both hind legs in this way, and when she arrives at the hive the nursing bees take the lumps from her, and eat it themselves, or mix it with honey to feed the young bees; or, when they have any to spare, store it away in old honey-cells to be used by and by. This is the dark, bitter stuff called "bee-bread," which you often find in a honey-comb, especially in a comb which has been filled late in the summer.

When the bee has been relieved of the bee-bread she goes off to one of the clean cells in the new comb and, standing on the edge, throws up honey from the honey-bag into the cell. One cell will hold the contents of many honey-bags, and so the bnsy little workers have to work all day filling cell after cell, in which the honey lies uncovered, being too thick and sticky to flow out, and is used for daily food—unless there is any to spare, and then they close up the cells with wax to keep for the winter.

Meanwhile, a day or two after the bees have settled in the

hive, the queen bee begins to get very restless. She goes outside the hive and hovers about a little while, and then comes in again, and though generally the bees all look very closely after her to keep her indoors, yet now they let her do as she likes. Again she goes out, and again back, and then, at last, she soars up into the air and flies away. But she is not allowed to go alone. All the drones of the hive rise up after her, forming a guard of honor to follow her wherever she goes.

In about half an hour she comes back again, and then the working bees all gather round her, knowing that now she will remain quietly in the hive and spend all her time in laying eggs; for it is the queen bee who lays all the eggs in the hive. This she begins to do about two days after her flight. There are now many cells ready besides those filled with honey; and, escorted by several bees, the queen bee goes to one of these, and putting her head into it, remains there a second, as if she were examining whether it would make a good home for the young bee. Then, coming out, she turns round and lays a small, oval, bluish-white egg in the cell. After this she takes no more notice of it, but goes on to the next cell and the next, doing the same thing, and laying eggs in all the empty cells equally on both sides of the comb. She goes on so quickly that she sometimes lays as many as two hundred eggs in one day.

Then the work of the nursing bees begins. In two or three days each egg has become a tiny maggot or larva, and the nursing bees put into its cell a mixture of pollen and honey which they have prepared in their own mouths, thus making a kind of sweet bath in which the larva lies. In five or six days the larva grows so fat upon this that it nearly fills the cell, and then the bees seal up the mouth of the cell with a thin cover of wax, made of little rings, and with a tiny hole in the center.

As soon as the larva is covered in, it begins to give out from its under-lip a whitish, silken film made of two threads of silk glued together, and with this it spins a covering or cocoon all round itself, and so it remains for about ten days more. At last, just twenty-one days after the egg was laid, the young bee is quite perfect, and begins to eat her way through the cocoon

and through the waxen lid, and scrambles out of her cell. Then the nurses come again to her, stroke her wings and feed her for twenty-four hours, and after that she is quite ready to begin work, and flies out to gather honey and pollen like the rest of the workers.

By this time the number of working bees in the hive is becoming very great, and the storing of honey and pollen-dust goes on very quickly. Even the empty cells which the young bees have left are cleaned out by the nurses and filled with honey; and this honey is darker than that stored in clean cells, and which we always call "virgin honey," because it is so pure and clear.

At last, after six weeks, the queen leaves off laying worker-eggs and begins to lay, in some rather larger cells, eggs from which drones, or male bees, will grow up in about twenty days. Meanwhile, the worker-bees have been building on the edge of the cones some very curious cells which look like thimbles hanging with the open side upward, and about every three days the queen stops laying drone-eggs and goes to put an egg in one of these cells. Notice that she waits three days between each of these peculiar layings, because we shall see presently that there is a good reason for her doing so.

The nursing bees take great care of these eggs, and instead of putting ordinary food into the cell, they fill it with a sweet, pungent jelly, for this larva is to become a princess and a future queen bee. Curiously enough, it seems to be the peculiar food and the size of the cell which makes the larva grow into a mother-bee which can lay eggs, for if a hive has the misfortune to lose its queen, they take one of the ordinary worker-larvæ and put it into a royal cell, and feed it with jelly, and it becomes a queen-bee. As soon as the princess is shut in like the others, she begins to spin her cocoon, but she does not quite close it as the other bees do, but leaves a hole at the top.

At the end of sixteen days after the first royal egg is laid, the eldest princess begins to try to eat her way out of her cell, and about this time the old queen becomes very uneasy, and wanders about distractedly. The reason of this is that there can never be two queen bees in one hive, and the queen knows

that her daughter will soon be coming out of her cradle and will try to turn her off her throne.. So, not wishing to have to fight for her kingdom, she makes up her mind to seek a new home and take a number of her subjects with her. If you watch the hive about this time, you will notice many of the bees clustering together after they have brought in their honey, and hanging patiently, in order to have plenty of wax ready to use when they start, while the queen keeps a sharp lookout for a bright, sunny day on which they can swarm; for bees will never swarm on a wet or doubtful day if they can possibly help it, and we can easily understand why, when we consider how the rain would clog their wings and spoil the wax under their bodies.

Meanwhile the young princess grows very impatient, and tries to get out of her cell, but the worker-bees drive her back, for they know there would be a terrible fight if the two queens met. So they close up the hole she has made with fresh wax, after having put in some food for her to live upon till she is released.

At last a suitable day arrives, and about ten or eleven o'clock in the morning the old queen leaves the hive, taking with her about 2,000 drones and from 12,000 to 20,000 worker-bees, which fly a little way, clustering round her till she alights on the bough of some tree, and then they form a compact swarm ready for a new hive or to find a home of their own.

Leaving them to go their way, we will now return to the old hive. Here the liberated princess is reigning in all her glory; the worker-bees crowd round her, watch over her, and feed her, as though they could not do enough to show her honor. But still she is not happy. She is restless, and runs about as if looking for an enemy, and she tries to get at the remaining royal cells where the other young princesses are still shut in. But the workers will not let her touch them, and at last she stands still and begins to beat the air with her wings and to tremble all over, moving more and more quickly, till she makes quite a loud, piping noise.

Hark! What is that note answering her? It is a low, hoarse sound, and it comes from the cell of the next eldest princess. Now we see why the young queen has been so rest-

less. She knows her sister will soon come out, and the louder and stronger the sound becomes within the cell, the sooner she knows the fight will have to begin. And so she makes up her mind to follow her mother's example and to lead off a second swarm. But she cannot always stop to choose a fine day, for her sister is growing very strong and may come out of her cell before she is off. And so the second, or *after swarm*, gets ready and goes away. And this explains why princesses' eggs are laid a few days apart, for if they were laid all on the same day, there would be no time for one princess to go off with a swarm before the other came out of her cell. Sometimes, when the workers are not watchful enough, two queens do meet, and then they fight till one is killed; or sometimes they both go off with the same swarm without finding each other out. But this only delays the fight till they get into the new hive; sooner or later one must be killed.

And now a third queen begins to reign in the old hive, and she is just as restless as the preceding ones, for there are still more princesses to be born. But this time, if no new swarm wants to start, the workers do not try to protect the royal cells. The young queen darts at the first she sees, gnaws a hole with her jaws, and, thrusting in her sting through the hole in the cocoon, kills the young bee while it is still a prisoner. She then goes to the next, and the next, and never rests till all the young princesses are destroyed. Then she is contented, for she knows no other queen will come to dethrone her. After a few days she takes her flight in the air with the drones, and comes home to settle down in the hive for the winter.

Then a very curious scene takes place. The drones are no more use, for the queen will not fly out again, and these idle bees will never do any work in the hive. So the worker-bees begin to kill them, falling upon them and stinging them to death, and, as the drones have no stings, they cannot defend themselves, and in a few days there is not a drone, nor even a drone-egg, left in the hive. This massacre seems very sad to us, since the poor drones have never done any harm beyond being hopelessly idle. But it is less sad when we know that they could not live many weeks, even if they were not attacked,

and, with winter coming, the bees could not afford to feed useless mouths, so a quick death is probably happier for them than starvation.

And now all the remaining inhabitants of the hive settle down to feeding the young bees and laying in the winter's store. It is at this time, after they have been toiling and saving, that we come and take their honey; and from a well-stocked hive we may even take thirty pounds, without starving the industrious little inhabitants. But then we must often feed them in return, and give them sweet syrup in the late autumn and the next early spring when they cannot find any flowers.

Although the hive has now become comparatively quiet and the work goes on without excitement, yet every single bee is employed in some way either out of doors or about the hive. Besides the honey collectors and the nurses, a certain number of bees are told off to ventilate the hive, for naturally where so many insects are packed closely together the heat will become very great, and the air impure and unwholesome. And the bees have no windows that they can open to let in fresh air, so they are obliged to fan it in from the one opening of the hive. The way in which they do this is very interesting. Some of the bees stand close to the entrance, with their faces toward it, and opening their wings, so as to make them into fans, they wave them to and fro, producing a current of air. Behind these bees, and all over the floor of the hive, there stand others, this time with their backs toward the entrance, and fan in the same manner, and in this way air is sent into all the passages.

Another set of bees cleans out the cells after the young bees are born, and makes them fit to receive honey, while others guard the entrance of the hive to keep away the destructive wax-moth, which tries to lay its eggs in the comb so that its young ones may feed on the honey. All industrious people have to guard their property against thieves and vagabonds, and the bees have many intruders, such as wasps and snails and slugs, which creep in whenever they get a chance. If they succeed in escaping the sentinel bees, then a fight takes place within the hive, and the invader is stung to death.

Sometimes, however, after they have killed the enemy, the

bees cannot get rid of his body, for a snail or slug is too heavy to be easily moved, and yet it would make the hive very unhealthy to allow it to remain. In this dilemma the ingenious little bees fetch the gummy "propolis" from the plant-buds and cement the intruder all over, thus embalming his body and preventing it from decaying.

And so the life of this wonderful city goes on. Building, harvesting, storing, nursing, ventilating, and cleaning from morn till night, the little worker bee lives for about eight months, and in that time has done quite her share of work in the world. Only the young bees, born late in the season, live on till the next year to work in the spring. The queen bee lives longer, probably about two years, and then she, too, dies, after having had a family of many thousands of children.

EVOLUTION AND NATURE STUDIES

The Massacre of the Males

From the "Life of the Bee"

By M. MAETERLINCK

IF skies remain clear, the air warm, and pollen and nectar abound in the flowers, the workers, through a kind of forgetful indulgence, or over-scrupulous prudence perhaps, will for a short time longer endure the importunate, disastrous presence of the males. These comport themselves in the hives as did Penelope's suitors in the house of Ulysses. Indelicate and wasteful, sleek and corpulent, fully content with their idle existence as honorary lovers, they feast and carouse, throng the alleys, obstruct the passages, and hinder the work; jostling and jostled, fatuously pompous, swelled with foolish, good-natured contempt; harboring never a suspicion of the deep and calculating scorn wherewith the workers regard them, of the constantly growing hatred to which they give rise, or of the destiny that awaits them. For their pleasant slumbers they select the snuggest corners of the hive; then, rising carelessly, they flock to the open cells where the honey smells sweetest. From noon till three, when the purple country trembles in blissful lassitude beneath the invincible gaze of a July or August sun, the drones will appear on the threshold. They have a helmet made of enormous black pearls, two lofty, quivering plumes, a doublet of iridescent, yellowish velvet, an heroic tuft, and a fourfold mantle, translucent and rigid. They create a prodigious stir, brush the sentry aside, overturn the cleaners, and collide with the foragers as these return laden with their humble spoil. They have the busy air, the extravagant, con-

temptuous gait of indispensable gods who should be simultaneously venturing towards some destiny unknown to the vulgar. One by one they sail off into space, irresistible, glorious, and tranquilly make for the nearest flowers, where they sleep till the afternoon freshness awakens them. Then, with the same majestic pomp, and still overflowing with magnificent schemes, they return to the hive, go straight to the cells, plunge their head to the neck in the vats of honey, and fill themselves tight as a drum to repair their exhausted strength; whereupon, with heavy steps, they go forth to meet the good, dreamless, and careless slumber that shall fold them in its embrace till the time for the next repast.

But the patience of the bees is not equal to that of men. One morning the long-expected word of command goes through the hive; and the peaceful workers turn into judges and executioners. Whence this word issues, we know not; it would seem to emanate suddenly from the cold, deliberate indignation of the workers; and no sooner has it been uttered than every heart throbs with it, inspired by the genius of the unanimous republic. One part of the people renounce their foraging duties to devote themselves to the work of justice. The great idle drones, asleep in unconscious groups on the melliferous walls, are rudely torn from their slumbers by an army of wrathful virgins. They wake, in pious wonder; they cannot believe their eyes; and their astonishment struggles through their sloth as a moonbeam through marshy water. They stare amazedly round them, convinced that they must be victims of some mistake; and the mother-idea of their life being first to assert itself in their dull brain, they take a step toward the vats of honey to seek comfort there. But ended for them are the days of May honey, the wine-flower of lime-trees and fragrant ambrosia of thyme and sage, of marjoram and white clover. Where the path once lay open to the kindly, abundant reservoirs, that so invitingly offered their waxen and sugary mouths, there stands now a burning bush all alive with poisonous, bristling stings. The atmosphere of the city is changed; in lieu of the friendly perfume of honey, the acrid odor of poison prevails; thousands of tiny drops glisten at the end of the

stings, and diffuse rancor and hatred. Before the bewildered parasites are able to realize that the happy laws of the city have crumbled, dragging down in most inconceivable fashion their own plentiful destiny, each one is assailed by three or four envoys of justice; and these vigorously proceed to cut off his wings, saw through the petiole that connects the abdomen with the thorax, amputate the feverish antennæ, and seek an opening between the rings of his cuirass through which to pass their sword. No defense is attempted by the enormous, but unarmed creatures; they try to escape, or oppose their mere bulk to the blows that rain down upon them. Forced onto their backs, with their relentless enemies clinging doggedly to them, they will use their powerful claws to shift them from side to side; or, turning on themselves, they will drag the whole group round and round in wild circles, which exhaustion soon brings to an end. And, in a very brief space, their appearance becomes so deplorable that pity, never far from justice in the depths of our heart, quickly returns, and would seek forgiveness, though vainly, of the stern workers who recognize only Nature's harsh and profound laws. The wings of the wretched creatures are torn, their antennæ bitten, the segments of their legs wrenched off; and their magnificent eyes, once mirrors of the exuberant flowers, flashing back the blue light and the innocent pride of summer, now, softened by suffering, reflect only the anguish and distress of their end. Some succumb to their wounds, and are at once borne away to distant cemeteries by two or three of their executioners. Others, whose injuries are less, succeed in sheltering themselves in some corner, where they lie, all huddled together, surrounded by an inexorable guard, until they perish of want. Many will reach the door, and escape into space, dragging their adversaries with them; but, toward evening, impelled by hunger and cold, they return in crowds to the entrance of the hive to beg for shelter. But there they encounter another pitiless guard. The next morning, before setting forth on their journey, the workers will clear the threshold, strewn with the corpses of the useless giants; and all recollection of the idle race disappears till the following spring.

EVOLUTION AND NATURE STUDIES

White Ants

By HENRY DRUMMOND

THE termite or white ant is a small insect, with a bloated, yellowish-white body, and a somewhat large thorax, oblong-shaped, and colored a disagreeable oily brown. The flabby, tallow-like body makes this insect sufficiently repulsive, but it is for quite another reason that the white ant is the worst abused of all living vermin in warm countries. The termite lives almost exclusively upon wood; and the moment a tree is cut or a log sawed for any economical purpose, this insect is upon its track. One may never see the insect, possibly, in the flesh, for it lives underground; but its ravages confront one at every turn. You build your house, perhaps, and for a few months fancy you have pitched upon the one solitary site in the country where there are no white ants. But one day suddenly the door-post totters, and lintel and rafters come down together with a crash. You look at a section of the wrecked timbers, and discover that the whole inside is eaten clean away. The apparently solid logs of which the rest of the house is built are now mere cylinders of bark, and through the thickest of them you could push your little finger. Furniture, tables, chairs, chests of drawers, everything made of wood, is inevitably attacked, and in a single night a strong trunk is often riddled through and through, and turned into matchwood. There is no limit, in fact, to the depredation by these insects, and they will eat books, or leather, or cloth, or anything; and in many parts of Africa I believe if a man lay down to sleep with a wooden leg, it would be a heap of sawdust in the morning. So much

feared is this insect now, that no one in certain parts of India and Africa ever attempts to travel with such a thing as a wooden trunk. On the Tanganyika plateau I have camped on ground which was as hard as adamant, and, apparently, as innocent of white ants as the pavement of St. Paul's; and wakened next morning to find a stout wooden box almost gnawed to pieces. Leather portmanteaus share the same fate, and the only substances which seem to defy the marauders are iron and tin.

But what has this to do with earth or with agriculture? The most important point in the work of the white ant remains to be noted. I have already said that the white ant is never seen. Why he should have such a repugnance to being looked at is at first sight a mystery, seeing that he himself is stone blind. But his coyness is really due to the desire for self-protection; for the moment his juicy body shows itself above ground, there are a dozen enemies waiting to devour it. And yet the white ant can never procure any food until it comes above ground. Nor will it meet the case for the insect to come to the surface under the shadow of night. Night in the tropics, so far as animal life is concerned, is as the day. It is the great feeding-time, the great fighting-time, the carnival of the carnivora, and of all beasts, birds, and insects of prey, from the least to the greatest. It is clear then that darkness is no protection to the white ant; and yet without coming out of the ground it cannot live. How does it solve the difficulty? It takes the ground out along with it. I have seen white ants working on the top of a high tree, and yet they were underground. They took up some of the ground with them to the tree-top; just as the Esquimaux heap up snow, building it into the low tunnel-huts in which they live, so the white ants collect earth, only in this case not from the surface, but from some depth underneath the ground, and plaster it into tunneled ways. Occasionally these run along the ground, but more often mount in endless ramifications to the top of trees, meandering along every branch and twig, and here and there debouching into large covered chambers which occupy half the girth of the trunk. Millions of trees in some districts are thus fantastically plastered over with tubes, galleries, and chambers of earth, and many pounds'

weight of subsoil must be brought up for the mining of even a single tree. The building material is conveyed by the insects up a central pipe with which all the galleries communicate, and which at the downward end connects with a series of subterranean passages leading deep into the earth. The method of building the tunnels and covered ways is as follows: At the foot of a tree the tiniest hole cautiously opens in the ground close to the bark. A small head appears, with a grain of earth clasped in its jaws. Against the tree trunk this earth-grain is deposited, and the head is withdrawn. Presently it reappears with another grain of earth; this is laid beside the first, rammed tight against it, and again the builder descends underground for more. The third grain is not placed against the tree, but against the former grain; a fourth, a fifth, and a sixth follow, and the plan of the foundation begins to suggest itself as soon as these are in position. The stones, or grains, or pellets of earth are arranged in a semicircular wall; the termite, now assisted by three or four others, standing in the middle between the sheltering wall and the tree, and working briskly with head and mandible to strengthen the position. The wall in fact forms a small moon-rampart, and as it grows higher and higher it soon becomes evident that it is going to grow from a low battlement into a long perpendicular tunnel running up the side of the tree. The workers, safely ensconced inside, are now carrying up the structure with great rapidity, disappearing in turn as soon as they have laid their stone, and rushing off to bring up another. The way in which the building is done is extremely curious, and one could watch the movements of these wonderful little masons by the hour. Each stone as it is brought to the top is first of all covered with mortar. Of course, without this the whole tunnel would crumble into dust before reaching the height of half an inch; but the termite pours over the stone a moist, sticky secretion, turning the grain round and round with its mandibles until the whole is covered with slime. Then it places the stone with great care upon the top of the wall, works it about vigorously for a moment or two till it is well jammed into its place, and then starts off instantly for another load.

Peering over the growing wall, one soon discovers one, two, or more termites of a somewhat larger build, considerably longer, and with a very different arrangement of the parts of the head, and especially of the mandibles. These important-looking individuals saunter about the rampart in the most leisurely way, but yet with a certain air of business, as if perhaps the one was the master of works and the other the architect. But closer observation suggests that they are in nowise superintending operations, nor in any immediate way contributing to the structure, for they take not the slightest notice either of the workers or the works. They are posted there in fact as sentries; and there they stand, or promenade about, at the mouth of every tunnel, like Sister Anne, to see if anybody is coming. Sometimes somebody does come, in the shape of another ant; the real ant this time, not the defenseless *Neuropteron*, but some valiant and belted knight from the warlike *Formicidæ*. Singly or in troops, this rapacious little insect, fearless in its chitinous coat of mail, charges down the tree trunk, its antennæ waving defiance to the enemy and its cruel mandibles thirsting for termite blood. The worker white-ant is a poor, defenseless creature, and, blind and unarmed, would fall an immediate prey to these well-drilled banditti, who forage about in every tropical forest in unnumbered legion. But at the critical moment, like Goliath from the Philistines, the soldier termite advances to the fight. With a few sweeps of its scythe-like jaws, it clears the ground, and while the attacking party is carrying off its dead, the builders, unconscious of the fray, quietly continue their work. To every hundred workers in a white-ant colony, which numbers many thousands of individuals, there are perhaps two of these fighting-men. The division of labor here is very wonderful; and the fact that besides these two specialized forms there are in every nest two other kinds of the same insect, the kings and queens, shows the remarkable height to which civilization in these communities has attained.

But where is this tunnel going to, and what object have the insects in view in ascending this lofty tree? Thirty feet from the ground, across innumerable forks, at the end of a long

branch, are a few feet of dead wood. How the ants know it is there, how they know its sap has dried up, and that it is now fit for the termites' food, is a mystery. Possibly they do not know and are only prospecting on the chance. The fact that they sometimes make straight for the decaying limb argues, in these instances, a kind of definite instinct; but, on the other hand, the fact that in most cases the whole tree, in every branch and limb, is covered with termite tunnels, would show perhaps that they work most commonly on speculation, while the number of abandoned tunnels, ending on a sound branch in a *cul de sac*, proves how often they must suffer the usual disappointments of all such adventurers. The extent to which these insects carry on their tunneling is quite incredible, until one has seen it in nature with his own eyes. The tunnels are perhaps about the thickness of a small-sized gas-pipe, but there are junctions here and there of large dimensions, and occasionally patches of earth-work are found, embracing nearly the whole trunk for some feet. The outside of these tunnels, which are never quite straight, but wander irregularly along stem and branch, resembles in texture a coarse sandpaper; and the color, although this naturally varies with the soil, is usually a reddish brown. The quantity of earth and mud plastered over a single tree is often enormous; and when one thinks that it is not only an isolated specimen here and there that is frescoed in this way, but often all the trees of a forest, some idea will be formed of the magnitude of the operations of these insects, and the extent of their influence upon the soil which they are ceaselessly transporting from underneath the ground.

In traveling through the great forests of the Rocky Mountains or of the Western States, the broken branches and fallen trunks, strewing the ground breast-high with all sorts of decaying litter, frequently make locomotion impossible. To attempt to ride through these western forests, with their meshwork of interlocked branches and decaying trunks, is often out of the question, and one has to dismount and drag his horse after him as if he were clambering through a wood-yard. But in an African forest not a fallen branch is seen. One is struck at first by a certain clean look about the great forests of the interior, a

novel and unaccountable cleanness, as if the forest bed was carefully swept and dusted daily by unseen elves. And so indeed it is. Scavengers of a hundred kinds remove decaying animal matter, from the carcass of a fallen elephant to the broken wing of a gnat; eating it, or carrying it out of sight and burying it in the deodorizing earth. And these countless millions of termites perform a similar function for the vegetable world, making away with all plants and trees, all stems, twigs, and tissues, the moment the finger of decay strikes the signal. Constantly, in these woods, one comes across what appear to be sticks and branches and bundles of fagots, but when closely examined, they are seen to be mere casts in mud. From these hollow tubes, which preserve the original form of the branch down to the minutest knot or fork, the ligneous tissue is often entirely removed, while others are met with in all stages of demolition. There is the section of an actual specimen, which is not yet completely destroyed, and from which the mode of attack may be easily seen. The insects start apparently from two centers. One company attacks the inner bark, which is the favorite morsel, leaving the coarse outer bark untouched, or more usually replacing it with grains of earth, atom by atom, as they eat it away. The inner bark is gnawed off likewise as they go along, but the woody tissue beneath is allowed to remain, to form a protective sheath for the second company, who begin work at the center. This second contingent eats its way outward and onward, leaving a thin tube of the outer wood to the last, as props to the mine, till they have finished the main excavation. When a fallen trunk lying upon the ground is the object of attack, the outer cylinder is frequently left quite intact, and it is only when one tries to drag it off to his camp-fire that he finds to his disgust that he is dealing with a mere hollow tube, a few lines in thickness, filled up with mud.

But the works above-ground represent only a part of the labors of these slow-moving but most industrious of creatures. The arboreal tubes are only the prolongation of a much more elaborate system of subterranean tunnels, which extend over large areas, and mine the earth sometimes to a depth of many feet or even yards.

The material excavated from these underground galleries and from the succession of domed chambers—used as nurseries or granaries—to which they lead, has to be thrown out upon the surface. And it is from these materials that the huge ant-hills are reared, which form so distinctive a feature of the African landscape. These heaps and mounds are so conspicuous that they may be seen for miles, and so numerous are they, and so useful as cover to the sportsman, that, without them, in certain districts hunting would be impossible. The first things, indeed, to strike the traveler in entering the interior are the mounds of the white ant, now dotting the plain in groups like a small cemetery, now rising into mounds, singly or in clusters, each thirty or forty feet in diameter and ten or fifteen in height; or again standing out against the sky like obelisks, their bare sides carved and fluted into all sorts of fantastic shapes. In India these ant-heaps seldom attain a height of more than a couple of feet, but in Central Africa they form veritable hills, and contain many tons of earth. The brick houses of the Scotch mission-station on Lake Nyassa have all been built out of a single ant's nest, and the quarry from which the material has been derived forms a pit beside the settlement some dozen feet in depth. A supply of bricks as large again could probably still be taken from this convenient depot; and the missionaries on Lake Tanganyika and onward to Victoria Nyanza have been similarly indebted to the labors of the termites. In South Africa the Zulus and Kaffirs pave all their huts with white-ant earth; and during the Boer war our troops in Pretoria, by scooping out the interior from the smaller beehive-shaped ant-heaps and covering the top with clay, constantly used them as ovens. These ant-heaps may be said to abound over the whole interior of Africa, and there are several distinct species. The most peculiar, as well as the most ornate, is a small variety from one to two feet in height, which occurs in myriads along the shores of Lake Tanganyika. It is built in symmetrical tiers, and resembles a pile of small rounded hats, one above another, the rims depending like eaves, and sheltering the body of the hill from rain. To estimate the amount of earth per acre raised from the water-line of the subsoil by white ants,

would not in some districts be an impossible task, and it would probably be found that the quantity at least equaled that manipulated in temperate regions by the earthworm.

These mounds, however, are more than mere waste-heaps. Like the corresponding region underground, they are built into a meshwork of tunnels, galleries, and chambers, where the social interests of the community are attended to. The most spacious of these chambers, usually far underground, is very properly allocated to the head of the society, the queen. The queen termite is a very rare insect, and as there are seldom more than one, or at most two, to a colony, and as the royal apartments are hidden far in the earth, few persons have ever seen a queen; and indeed most, if they did happen to come across it, from its very singular appearance, would refuse to believe that it had any connection with white ants. It possesses indeed the true termite head, but there the resemblance to the other members of the family stops; for the size of the head bears about the same proportion to the rest of the body as does the tuft on his Glengarry bonnet to a six-foot Highlander. The phenomenal corpulence of the royal body in the case of the queen termite is possibly due in part to want of exercise; for, once seated upon her throne, she never stirs to the end of her days. She lies there, a large, loathsome, cylindrical package, two or three inches long, in shape like a sausage, and as white as a bolster. Her one duty in life is to lay eggs; and it must be confessed she discharges her function with complete success, for in a single day her progeny often amounts to many thousands, and for months this enormous fecundity never slackens. The body increases slowly in size, and through the transparent skin the long folded ovary may be seen, with the eggs, impelled by a peristaltic motion, passing onward for delivery to the workers, who are waiting to carry them to the nurseries, where they are hatched. Assiduous attention, meantime, is paid to the queen by other workers, who feed her diligently, with much self-denial, stuffing her with morsel after morsel from their own jaws. A guard of honor in the shape of a few of the larger soldier ants is also in attendance, as a last and almost unnecessary precaution. In addition finally, to the

soldiers, workers, and queen, the royal chamber has also one other inmate—the king. He is a very ordinary-looking insect, about the same size as the soldiers, but the arrangement of the parts of the head and body is widely different, and, like the queen, he is furnished with eyes.

EVOLUTION AND NATURE STUDIES

The Habits of Ants

By SIR JOHN LUBBOCK

THE communities of ants are sometimes very large, numbering even up to 500,000 individuals; and it is a lesson to us, that no one has ever yet seen a quarrel between any two ants belonging to the same community. On the other hand, it must be admitted that they are in hostility not only with most other insects, including ants of different species, but even with those of the same species, if belonging to different communities. I have over and over again introduced ants from one of my nests into another nest of the same species; and they were invariably attacked, seized by a leg or an antenna, and dragged out.

It is evident, therefore, that the ants of each community all recognize one another, which is very remarkable. But more than this, I have several times divided a nest into two halves, and found that even after a separation of a year and nine months they recognized one another, and were perfectly friendly; while they at once attacked ants from a different nest, although of the same species.

It has been suggested that the ants of each nest have some sign or password by which they recognize one another. To test this I made some insensible. First I tried chloroform; but this was fatal to them, and I did not consider the test satisfactory. I decided therefore to intoxicate them. This was less easy than I had expected. None of my ants would voluntarily degrade themselves by getting drunk. I got over the difficulty, however, by putting them into whisky for a few

moments. I took fifty specimens—twenty-five from one nest and twenty-five from another—made them dead drunk, marked each with a spot of paint, and put them on a table close to where other ants from one of the nests were feeding. The table was surrounded as usual with a moat of water to prevent them from straying. The ants which were feeding soon noticed those which I had made drunk. They seemed quite astonished to find their comrades in such a disgraceful condition, and as much at a loss to know what to do with their drunkards as we are. After a while, however, to cut my story short, they carried them all away; the strangers they took to the edge of the moat and dropped into the water, while they bore their friends home into the nest, where by degrees they slept off the effects of the spirit. Thus it is evident that they know their friends even when incapable of giving any sign or password.

This little experiment also shows that they help comrades in distress. If a wolf or a rook be ill or injured, we are told that it is driven away or even killed by its comrades. Not so with ants. For instance, in one of my nests an unfortunate ant, in emerging from the chrysalis skin, injured her legs so much that she lay on her back quite helpless. For three months, however, she was carefully fed and tended by the other ants. In another case, an ant had injured her antennæ in the same manner. I watched her also carefully to see what would happen. For some days she did not leave the nest. At last one day she ventured outside, and after a while met a stranger ant of the same species, but belonging to another nest, by whom she was at once attacked. I tried to separate them; but, whether by her enemy or, perhaps, by my well-meant but clumsy kindness, she was evidently much hurt, and lay helplessly on her side. Several other ants passed her without taking any notice; but soon one came up, examined her carefully with her antennæ, and carried her off tenderly to the nest. No one, I think, who saw it could have denied to that ant one attribute of humanity, the quality of kindness.

The existence of such communities as those of ants or bees implies, no doubt, some power of communication; but the amount is still a matter of doubt. It is well known that if one

bee or ant discovers a store of food, others soon find their way to it. This, however, does not prove much. It makes all the difference whether they are brought or sent. If they merely accompany, on her return, a companion who has brought a store of food, it does not imply much. To test this, therefore, I made several experiments. For instance, one cold day my ants were almost all in their nests. One only was out hunting, and about six feet from home. I took a dead bluebottle fly, pinned it onto a piece of cork, and put it down just in front of her. She at once tried to carry off the fly, but to her surprise found it immovable. She tugged and tugged, first one way and then another, for about twenty minutes, and then went straight off to the nest. During that time not a single ant had come out; in fact, she was the only ant of that nest out at the time. She went straight in; but in a few seconds—less than half a minute—came out again with no less than twelve friends, who trooped off with her, and eventually tore up the dead fly, carrying it off in triumph.

Now, the first ant took nothing home with her; she must therefore somehow have made her friends understand that she had found some food, and wanted them to come and help her to secure it. In all such cases, however, so far as my experience goes, the ants brought their friends; and some of my experiments indicated that they are unable to send them.

Certain species of ants, again, make slaves of others, as Huber first observed. If a colony of the slave-making ants is changing the nest—a matter which is left to the discretion of the slaves—the latter carry their mistresses to their new home. Again, if I uncovered one of my nests of the fuscous ant (*Formica fusca*), they all began running about in search of some place of refuge. If now I covered over one small part of the nest, after a while some ant discovered it. In such a case, however, the brave little insect never remained there; she came out in search of her friends, and the first one she met she took up in her jaws, threw over her shoulder (their way of carrying friends), and took into the covered part; then both came out again, found two more friends and brought them in, the same maneuver being repeated until the whole community was

in a place of safety. This, I think, says much for their public spirit; but seems to prove that — in *F. fusca* at least — the powers of communication are but limited.

One kind of slave-making ant has become so completely dependent on their slaves, that even if provided with food they will die of hunger, unless there is a slave to put it into their mouths. I found, however, that they would thrive very well if supplied with a slave for an hour or so once a week to clean and feed them.

But in many cases the community does not consist of ants only. They have domestic animals; and indeed it is not going too far to say that they have domesticated more animals than we have. Of these the most important are aphides. Some species keep aphides on trees and bushes, others collect root-feeding aphides into their nests. They serve as cows to the ants, which feed on the honey-dew secreted by the aphides. Moreover the ants not only protect the aphides themselves, but also collect their eggs in autumn and tend them carefully through the winter, ready for the next spring. Of the other insects domesticated by ants some, from living constantly underground, have completely lost their eyes and become quite blind.

But I must not let myself be carried away by this fascinating subject, which I have treated more at length in another work. I will only say that though their intelligence is no doubt limited, still I do not think that any one who has studied the life-history of ants can draw any fundamental line of separation between instinct and reason.

When we see a community of ants working together in perfect harmony, it is impossible not to ask ourselves how far they are mere exquisite automatons, how far they are conscious beings. When we watch an ant-hill tenanted by thousands of industrious inhabitants, excavating chambers, forming tunnels, making roads, guarding their home, gathering food, feeding the young, tending their domestic animals—each one fulfilling its duties industriously, and without confusion—it is difficult altogether to deny to them the gift of reason; and all our recent observations tend to confirm the opinion that their mental powers differ from those of men not so much in kind as in degree.

EVOLUTION AND NATURE STUDIES

Spiders and Their Ways

By MARGARET WENTWORTH LEIGHTON

Spider,
At my window spinning,
Weaving circles wider, wider,
From the deft beginning;

Running
Rings and spokes, until you
Build your silken death-trap cunning—
Shall I catch you—kill you?

Sprawling,
Nimble, shrewd as Circe;
Death's your only aim and calling,
Why should you have mercy?

Strike thee?
Not for rapine willful:
Man himself is too much like thee,
Only not so skillful.

—GEORGE HORTON'S *Songs of the Lowly.*

NOT so skillful, and doubtless never will be, for to-day a spider's thread is used in the telescope because man has been unable to manufacture one so fine and delicate.

Whenever I look at the marvelous web of the great black-and-gold garden spider I remember that pretty story of the way in which the group of spiders received its name of *Arachnidæ.* In the olden times there was a lovely maiden named

Arachne, who could weave and embroider with such deftness that the nymphs all gathered to watch her. They whispered to each other that she must have been taught by Minerva herself, who was the goddess of Wisdom. Arachne overheard them, and, denying their accusation, challenged Minerva to a trial of skill. Minerva accepted the challenge, and when the webs were woven Arachne's was wonderfully beautiful, but Minerva's far surpassed it. Arachne was in despair and hung herself, whereupon Minerva's chagrin was so great that she transformed her into a spider, and her descendants preserve much of her skill.

We are apt to think of spiders as insects, but really they are only distantly related to insects, their first cousins being scorpions and king crabs. The spider's body consists of two parts. It has four pairs of legs, a pair of palpi, and a pair of mandibles. The legs are jointed, and on the last joint there are three claws. The palpi are used as feelers and to hold the food. The breathing apparatus of the spider is a combination of lungs and gills. It has glands containing poison which lie partly in the head and partly in the basal joint of the mandibles. There is a tiny opening in the claw on the mandible, out of which the poison flows when the spider captures its prey. It has eight eyes. The spiders are classified largely by the different arrangements and grouping of the eyes. Some have them in one or more clusters, some in rows, and others scattered about. They appear to be able to see as well by night as by day. Near the end of the body are the spinnerets—two, three, or four pairs—out of which the silk comes for weaving the webs, nests, and egg cocoons.

Usually the female spider is much larger and stronger than the male. One naturalist thus graphically describes their wedded life: "Their honeymoon is of short duration, and is terminated by the bride's banqueting on the bridegroom. Doubtless she evinces taste and discrimination in her appreciation of a 'nice young man.'"

Spiders, like lobsters and other crustaceans, have the power of reproducing certain parts if they happen to meet with an injury, as legs, palpi, and spinnerets.

We find as marked differences in habits, tastes, and characters among spiders as among human beings. Some kinds prefer always living in houses or cellars, not seeming to care for any fresh air or out-of-door exercise. Mr. Jesse tells of two spiders that lived for thirteen years in opposite corners of a drawer which was used for soap and candles. Others delight in making burrows in the earth, in dwelling under stones or behind the loose bark on trees, and others live under water. Many never leave their webs, but patiently wait, hoping some insect will become entangled in the snares they have set. Others dash about and seize upon every luckless insect that crosses their path. The most adventurous of all are those that sail out into the world on one of their own little threads. Darwin tells of encountering thousands of them many leagues from land when he was taking his famous voyage in the "Beagle." He says: "The little aeronaut, as soon as it arrived on board, was very active, running about, sometimes letting itself fall, then reascending the same thread. It could run with facility on the surface of the water."

In the bright autumn weather, if we observe closely, we may sometimes see some of our own small spiders ascend to the tops of trees, fences, and other high objects, rise on their toes, turn the spinners upward, throw out a quantity of silk, and sail away. They can be seen plentifully any fine day in October or November, before the cold weather, on Boston Common. They grasp the silken thread with their feet and seem to be enjoying themselves as much as the birds and butterflies.

Many instances are recorded of music-loving spiders, perhaps the most interesting being that related by Beethoven's biographer, who says: "A spider weaving its skillful, though delicate, trap for its daily dinner worked industriously in the corner of the ceiling until Beethoven began to play. Beethoven, who at that time had not thousands hanging on his baton, was rather pleased and attached to this listener, which most practically proved the value it attached to the performance by risking its life in coming nearer the enchanted instrument. And ill was it rewarded. The mother one day, perceiving the ugly

animal, seized and killed it. But the boy Beethoven was so put out and so miserable at losing his strange auditor that he burst into tears and, seizing his violin, smashed it against the floor, shivering it into a thousand pieces."

Many kinds build their webs and cocoons in exposed places and take no pains to conceal them, while others cover theirs with tiny pebbles and bits of earth for protection. Some kinds of spiders abandon their egg cocoon as soon as it is finished, while others carry it about with them until the babies appear. One mother allowed herself to be torn to pieces rather than leave her cocoon.

We might compare the spider's different modes of getting about to those of the birds. The hunting spiders leap and hop, the house spiders generally run forward, other kinds run backward and sideways with equal facility, and some, as we have seen, float about in the air. The most marvelous of the spiders' gifts is the silk-spinning. The spinnerets or spinners are little organs at the hind end of the body. Each has a number of very minute holes in it. Out of these the silk flows in a liquid form, but as soon as the air strikes it it hardens into a thread. The strands from the different holes all unite and form what we know as the spider's thread. There are great differences in the kinds of webs and nests which different spiders make. One of the most interesting is the web of the great black-and-gold garden spider. First she spins several lines all joined in the center like the spokes of a wheel, and attached to stems or leaves of plants at the outer edges. When the rays are finished she begins at the middle to make the spiral part. It is fascinating to watch her, as she crosses each spoke, stop and pat down the silk once or twice, then pull it to see if it is well secured before passing to the next one. When the web is finished, she makes a zigzag ladder of white silk, running from the bottom outer edge to the center. When she hangs in the middle of her web, as she does much of the time, the ladder helps to conceal her. The web is made of two kinds of silk—one smooth, the other covered with an adhesive liquid. When the insects are caught, their legs and wings are soon covered with the sticky juice, so that it is impossible for them

to escape. The spider, knowing it would not be convenient to become entangled herself, spins one long, smooth thread from the center to the outside, which she uses in traveling to and fro.

The common house spider is wonderfully sagacious. Once in a while a large insect is caught in her web. She wants to take it up to her inner retreat to devour, and it is too heavy for her to carry. What is she to do? First she bites its leg, injecting some of her poison, which stupefies it. Next she throws some additional threads about it and ascends to the top, pulling the thread as hard as she can. When she has rested for a little time, she winds more threads about her victim and pulls again, each time attaching the threads at the top. In this way she finally succeeds in hoisting her feast into her house, though the process may last several days.

Who would think that our predecessors in the art of curling the hair were spiders? One species has been provided by Nature with a sort of little curling comb called the *calimistra*. It is on the hind legs and consists of two rows of parallel spines. The web, which she makes of bluish-white silk, is unusually pretty, as each thread is gracefully curled by drawing it between the spines.

Thoreau calls the little gossamer webs which we see spread over the grass on a dewy morning the napkins of the fairies. Even Chaucer, who wrote five hundred years ago, mentions them as a great curiosity to the people of his time. He says:

> As sore wondren som on cause of thonder,
> On ebb and flood, on gossamer and on mist,
> And on all thing, 'til that the cause is wist.

A hundred and fifty years ago a Frenchman, M. Le Bon, made some stockings, purses, and gloves from spiders' silk. The Bermuda ladies use the thread of *Nephila* for sewing, and Queen Victoria was presented by the Empress of Brazil with a dress made of spiders' silk.

Spiders molt several times, each time appearing in a different color. We should hardly expect to find very brilliant or showy colors among them, yet some of them are gorgeous in the extreme. A little crab spider that built a house in my gar-

den was the brightest lemon-yellow all over, and shone like a jewel amid the dark green of the surrounding foliage.

One of the English spiders has a black head and thorax, with an orange-red body, on which are six black spots, each ringed with white; another has a green coat with brilliant red and yellow striped trousers, for all the world like a king's jester. One dainty lady is clad in violet and white, a flaunting miss in black and flame-color, and her sister in cherry and brown.

Some of the *Thomisidæ* are the exact colors of certain flowers, in the centers of which they sit all day, watching for the insects that come to get honey.

Two of the spiders' worst enemies are mud wasps and ichneumon flies. In searching recently for spiders beneath the clapboards on the south side of the house, I came across one of those curious structures which the mud wasp builds. I broke it open, and out tumbled a quantity of small spiders. The wasp's storehouse was in three compartments, and all together contained forty-nine spiders, all of the same kind and about the same size, in a torpid condition. The wasp had laid an egg in each of these spiders. She does not kill the spider, but merely stupefies it, so that when her egg hatches the larva may feed upon the luckless spider.

If one be a student of Nature he will perhaps have noticed a spider rush away and hide in her crack without any apparent reason. The moment before she had been enjoying the bright sunshine, and the student wonders why she ran away. The spider's perceptions are so keen that she knows long before he does that the sky will soon be overcast and torrents of rain descend or a cold wind begin to blow. If she stayed out she might soon be benumbed and unable to run into her house.

The water spiders are covered with hairs which shed the water, so that they never get wet. The little house under the water in which they live and raise their families is as snug and dry inside as yours and mine.

No spiders are more interesting than the trapdoor spiders and their first cousins the tarantulas. The former live in Europe and California. First, they make a burrow in the ground and then build the door. The California ones make

their door of mud and sticks. It fits into the tube as a cork does into a bottle. The covers built by the European species are mere little lids, but they are always built so as to resemble the surrounding surface. One kind shows her sagacity by building a sort of double door, by which she can escape should an enemy storm her fort. At the surface is the usual door, and a few inches below this another. When the spider hears an enemy investigating her burrow, she runs below the second door and pushes it up, so that the marauder will think he has happened upon a empty nest, the second door forming the bottom of it. The babies are born in the tubes, and remain with their mother until they are able to make nests for themselves.

These spiders spend the days in their burrows, but at night they all flock out to enjoy themselves. They fasten open their doors and make little webs over the grass. Many night-wandering beetles are caught, and then comes the banquet, which consists of the softer parts of the beetles. In the morning the closest observer could not find a trace of the preceding night's revelry, so carefully have the spiders cleared away all webs, beetle legs, and wing covers.

One group of spiders is called *Lycosa*, which means wolf spider. Perhaps they were named from the similarity of their habits to those of the wolf, being like him wandering and predaceous.

One of these is the tarantula, a great hairy fellow who inhabits warm countries. The species received its name from the Italian city of Tarentum, where they have been found in large numbers. There is a curious superstition connected with the tarantula's bite. If a person was bitten it was thought nothing could save his life but the playing of some lively dancing tunes. When he heard these he was supposed to be unable to resist the temptation to dance. Thus he grew very warm, and the perspiration came out in great beads all over him, each bead filled with poison. After he had danced as long as he possibly could, the poison had all escaped from his system. The tarantulas feed on small birds as well as insects. Indeed, one of the great southern species is called the bird-catching spider.

In India, where all animals are treated with consideration and even reverence, the little children often keep these spiders for pets. They tie a cord round a spider and lead it about, feeding it with worms and insects. Mother *Lycosa* always carries her egg cocoons out with her on her hunting expeditions, attached to the spinnerets.

One summer I kept a garden spider for three weeks under a tumbler, and had the pleasure of watching her building her house of snowy silk, with its three entrances, and raising a large family of children. She soon learned to take flies from my hand and drink water from a leaf which I gave her fresh every day. After a time she seemed to languish and droop, so I set her free in the garden once more.

> If you wish to live and thrive,
> Let a spider run alive.

says the old Kentish proverb.

EVOLUTION AND NATURE STUDIES

The Nocturnal Migration of Birds

By FRANK M. CHAPMAN

NO branch of ornithology offers more attractions to the student of birds than the fascinating subject of migration. Birds come and go; absent to-day, to-morrow they greet us from every tree and hedgerow. Their departure and arrival are governed by as yet unknown laws; their journeys though the pathless sky are directed by an instinct or reason which enables them to travel thousands of miles to a winter home, and in the spring to return to the nest of the preceding year. Volumes have been written to explain their mysterious appearances and disappearances.

Theories almost as numerous as the essays themselves have been advanced to account for the phenomena of migration. From the time of Jeremiah (viii. 7) to the present day we might cite a host of authors who have contributed to the literature of the subject. It is not our intention, however, to review the whole question of migration. The combined researches of ornithologists have placed it among the sciences, and its more prominent facts are common knowledge. We desire here to call attention to but one phase of the study, and more especially to outline some recent investigations in connection with the nocturnal migrations of birds.

From the nature of the case, our data concerning these night flights have long been meager and unsatisfactory. Even now our information has but reached a stage which permits us to intelligently direct further effort.

We know that the land birds which migrate by night in-

clude species of more or less retiring disposition, whose comparatively limited powers of flight would render them easy victims for birds of prey if they ventured far from the protection of their natural haunts during the day. Thus we find that the bush- or tree-loving thrushes, wrens, warblers, and vireos all choose the night as the most advantageous time in which to make their long semi-annual pilgrimage, while such bold rovers as swallows, swifts, and hawks migrate exclusively by day.

The information we possess concerning the manner in which the first-mentioned class of birds accomplish a journey which leads them from boreal regions to the tropics, has been derived from three sources: First, through the birds which are killed by striking lighthouses or electric-light towers; second, through observations made at night from similar structures; and, third, through the use of the telescope.

It has long been known that lighthouses are most destructive to night-migrating birds. Probably no one artificial cause produces more disastrous results than these beacons which guide the mariner in safety, but prove fatal obstacles in the path of aerial voyagers.

The number of birds killed by striking lighthouses is incalculable. Over fifteen hundred have been found dead at the foot of the Bartholdi statue in a single morning; while from Fire Island (Long Island) light we have a record of two hundred and thirty birds of one species—black-poll warblers which met their fate on the night of September 30, 1883.

Reports from numerous lighthouses show (1) a great variation in avian mortality at different localities; (2) that as a rule no birds are killed during clear nights; and (3) that comparatively few birds strike the lights during the vernal migration. The fact that birds follow certain routes or highways of migration in their journeys to and from the South doubtless explains their absence or presence at a given locality; indeed, it has been definitely ascertained that lights which are situated in known lines of migration—as for example, the Bartholdi statue at the mouth of the Hudson River valley—prove far more destructive than those which are placed far from the regular routes of migrating birds.

Through telescopic observations, to be mentioned later, we have learned that when *en route* birds travel at an altitude of from one to three miles above the earth. It is obvious, then, that when their way is not obscured by low-hanging clouds they pass too far above us to be attracted by terrestrial objects. It has been noted that cloudy and especially rainy nights are most disastrous to migrants, evidently because the formation of moisture at the elevation at which they are flying must not only interfere with their progress, but, also because, in veiling the earth below, it robs them of their landmarks, while the condensation of this moisture into rain presents an effectual check to flight. The birds then descend to a lower altitude, and, should the storm be very severe, they are obliged to seek the nearest shelter, and may even be driven to earth wet, helpless, and dying.

The influence thus shown to be exerted by meteorological conditions is the best explanation of the comparatively small number of birds killed during the spring migration, when the infrequency of violent storms enables them to perform their journey with less danger from exposure to the elements.

The observations of Mr. William Brewster on the migration of birds at the Point Lepreaux (Bay of Fundy) lighthouse have never been exceeded in interest or value by the recorded experiences of any other observer of similar phenomena. Still, even his graphic account fails to produce the sensations which possess one when for the first time the air at night is actually seen to be filled with the tiny songsters which before were known only as timid haunters of woods and thickets.

On September 26, 1891, it was the writer's good fortune to pass the night with several ornithologists at the Bartholdi statue in observing the nocturnal flight of birds. The weather was most favorable for our purpose. From the balcony at the base of the statue we saw the first bird enter the rays of light thrown out by the torch, one hundred and fifty feet above us, at eight o'clock. During the two succeeding hours birds were constantly heard and many were seen. At ten o'clock a light rain began to fall and for three hours it rained intermittently. Almost simultaneously there occurred a marked increase in

the number of birds seen about the light, and within a few minutes there were hundreds where before there was one, while the air was filled with the calls and chirps of the passing host.

The birds presented a singular appearance. As they entered the limits of the divergent rays of light they became slightly luminous, but as their rapid wing-beats brought them into the glare of the torch they reflected the full splendor of the light, and resembled enormous fireflies or swarms of huge golden bees.

At eleven o'clock we climbed to the torch and continued our observations from the balcony by which it is encircled. The scene was impressive beyond description; we seemed to have torn aside the veil which shrouds the mysteries of the night, and in the searching light reposed the secrets of Nature. As the tiny feathered wanderers emerged from the surrounding blackness, appeared for a moment in the brilliant halo about us, and continuing their journey were swallowed up in the gloom beyond, one marveled at the power which guided them thousands of miles through the trackless heavens. While by far the larger number hurried onward without pausing to inspect this strange apparition, others hovered before us like humming-birds before a flower, then wheeling, retreated for a short distance and returned to repeat the performance or pass us as did the first class mentioned, while others still, and the number was comparatively insignificant, struck some part of the torch either slightly or with sufficient force to cause them to fall stunned or dying. It was evidently by the merest accident that they struck at all; and, so far as we could judge, they were either dazzled by the rays of the light and thus unwittingly flew directly at the glass which protects it, or came in contact with some unilluminated part of the statue. During the two hours we were in the torch thousands of birds passed within sight, but less than twenty were killed.

This fact, in connection with the comparative or entire absence of birds on clear nights, very plainly shows that conclusions based solely on these casualties may be not only misleading but also erroneous. In other words, the number of birds

which strike a light is a poor index to the number which have flown by or above it in safety.

Throughout the evening there was a more or less regular fluctuation in the number of birds present; periods of abundance were followed by periods of scarcity, and the birds passed in well-defined flights, or loose companies, probably composed in the main of individuals which had started together.

The birds chirped and called incessantly. Frequently, when few could be seen, hundreds were heard passing in the darkness; the air was filled with the lisping notes of warblers and the mellow whistle of thrushes, and at no time during the night was there perfect silence. At daybreak a few stragglers were still winging their way southward, but before the sun rose the flights had ceased. The only birds identified were several species of warblers and thrushes, one red-eyed vireo, two golden-winged woodpeckers, one catbird, one whip-poor-will, and one bobolink. The most interesting and important results of the night's observations were the immediate effect of rainfall in forcing birds to migrate at a lower level, the infrequency with which they struck the torch, the immense number which passed beyond its rays, and the constancy with which they called and chirped as they flew.

An almost virgin field awaits the investigator who will systematically observe night-migrating birds with the aid of a telescope. Messrs. Allen and Scott, at Princeton, and the writer, assisted by Mr. John Tatlock, Jr., at Tenafly, New Jersey, and at the Columbia College Observatory, have alone recorded the results of observations of this nature. Their labors, however, were too brief to show more than the possibilities which await more extended effort.

A comparatively low-power glass is focused upon the moon, the birds appearing silhouetted upon its glowing surface as they cross the line of vision. Some idea of the multitude of feathered forms which people the upper regions of the air at night may be formed when it is stated that during three hours' observation at Tenafly no less than two hundred and sixty-four birds were seen crossing the restricted field included in the angle subtended by the full moon. Under proper focal condi-

tions, birds were so plainly visible that in many instances marked character of flight or form rendered it possible to recognize the species. Thus ducks, snipe, and sora rail were distinguished with certainty.

The effect on the observer of this seeing of things unseen is not a little curious, and may be likened to the startling disclosures which a high-power microscope presents in a drop of water.

From calculations based on an assumption that birds were not visible beyond a distance of five miles, we determined the greatest altitude at which birds migrate to be three miles above the earth's surface. Many, however, fly at a lower level; indeed, it is not improbable that certain species may, with more or less regularity, travel at a given altitude, and that this altitude may vary among birds of different families. With little doubt thrushes and warblers travel at a much lower level than do ducks and geese, a circumstance which may account for the great abundance of the first two named and the comparative absence of the last in the vicinity of lighthouses.

Such, in brief, are the sources and methods to which we owe our knowledge of the nocturnal flight of birds. It will be evident to the most casual reader how incomplete are our data. The time is still far distant when we can hope to account conclusively for the many perplexing phenomena of migration, but we may be pardoned if, in conclusion, we briefly review the bearing of our present information.

We need not discuss here the origin of migration or the causes which now induce birds to undertake a long and perilous journey twice each year. But the power and influences which guide a bird, in the darkness of the night, through space, and render a definite migration possible, are subjects kindred to our inquiry and worthy our attention.

Until we possess some exact knowledge of the distance to which birds can see we cannot estimate the aid their vision is to them while migrating. We know, however, that the avian eye is far more powerful than ours, and it is fair to assume that to some extent their journeys are directed by a sight which enables them to follow mountain chains, river valleys, and

coast lines, and to distinguish distant headlands or islands. At an altitude of two miles an object would be visible ninety miles and the horizon be separated by twice this distance. At no time, therefore, in their journey from North to South America are birds necessarily out of sight of land. But that they do venture beyond a point where land is visible is shown by the regular appearance of migrants in the Bermudas, six hundred miles from our coast, while Jamaica, four hundred miles north of the nearest point of South America, is a point of departure for many south-bound migrants. Here, with neither islet, shoal, nor reef to mark the way, it is evident that sight alone would prove an insufficient guide, and they must rely on some other sense. Primarily, this is the inherited habit which prompts birds to fly southward in the fall and to return in the spring. But, given the impulse of direction, there is little doubt that one of the best guides to night-flying birds is the sense of hearing. Birds' ears are exceedingly acute. They readily detect sounds which to us are inaudible. Almost invariably they will respond to an imitation of their notes. We have seen that when under way they constantly chirp and call, and when we take into consideration their aural power and their abundance in highways of migration, it is probably that at no time during the night is a bird out of hearing of its fellow-travelers. The line of flight once established, therefore, presumably by the older and more experienced birds, it becomes a comparatively easy matter for the novice to join the throng.

EVOLUTION AND NATURE STUDIES

Wingless Birds

By PHILIPPE GLANGEAUD

IT is often said that there are no rules without exceptions. We purpose to test the truth of this maxim once more. Fishes are made to live in water, but some of them pass the greater part of their existence in mud. Some even perch upon trees, thus competing with birds, whose kingdom is the air, and which are able, with the aid of their wings, to plunge into space and travel rapidly over considerable distances. Yet there are birds, deprived by Nature, which do not possess the wing characteristic of the feathered tribe, and are, consequently, like the majority of animals, pinned to the soil.

Birds do not all have equal power of flight, which is closely related to the extent of the development of their wings. There exist all grades in the spread of wings, between that of the condor, which is four times the length of the body, whereby the bird is able to rise to the height of nearly twenty-five thousand feet, and the little winglets of the auk, which are of no use to it. The penguins have still smaller wings, which are nothing more than short, flattened stumps, without proper feathers and covered with a fine, hairlike down which might be taken for scales.

Another group of birds exists, called appropriately *Brevipennes*, the wings of which are so poorly developed as to be wholly unsuitable for flight. As an offset and just compensation for this, their long and robust legs permit them to run with extraordinary speed. For that reason they have been called running birds, in distinction from other kinds that con-

stitute the group of flying birds. Among them are some gigantic birds, and also some that have no visible wings on the outside of their bodies, and may therefore be properly called wingless.

The ostrich is a member of this group. With its bare, callous head and short bill, its long, featherless neck, and its massive body, supported by long, half-bare legs, ending in two large toes; its very short wings, formed of soft and flexible feathers; and its plume-shaped tail, it presents a very special appearance among the birds.

The nandous, the American representatives of the ostrich, have still shorter wings, which have no *remigia* at all, and terminate in a horny appendage; they have no tail feathers.

The cassowary and the emu also resemble the ostrich in many points, but their wings are still more reduced than those of the nandou. They are only slightly distinct, and cannot be seen when the bird holds them close to its body. In the *Apteryx*, the name of which, from the Greek, means without wings, the organs of flight are hardly apparent, and consist simply of a very short stump bearing a thick and hooked nail. The *Apteryx*, which is also called *Kiwi*, a native of New Zealand, is the most singular of living birds. The neck and the body are continuous, and the moderately sized head is furnished with a long beak resembling that of the ibis. Having long hairs similar to the mustaches of cats at its base, it is different from the bills of all other existing birds in possessing nostrils that open at its upper point. Although the *Apteryx* cannot fly, it runs very fast, despite the shortness of its legs, and can defend itself very effectively against assailants by the aid of its long-nailed and sharp-nailed feet. The tail is absent like the wings. The very pliant feathers are extremely curious, of the shape of a lance-head, pendant, loose, silky, with jagged barbs, and increase in length as they go back from the neck. The bird is of the size of a fowl, and when in its normal position stands with its body almost vertical, and carries the suggestion of a caricature—resembling, we might say, a feathered sack, with only a long-billed head and the claws projecting, so that one beholding it feels that he is looking at some unfinished crea-

ture. It is a nocturnal bird, of fierce temper, and has become rare in consequence of the merciless war that is made upon it. Everything is strange about it, even the single egg it lays, which weighs about a quarter as much as its body.

Together with the *Apteryx* there lived, in New Zealand a bird that reached the height of nearly twelve feet—the *Dinornis*. It and the *Phororhaces* and the *Brontornis*, which have been recently exhumed in Patagonia, might be regarded as the giants of birds. This bird was known to the natives as the *Moa*, and lived in troops like the ostriches. Its organization was very much like that of the *Apteryx*, from which it was distinguished, however, by its great size, long neck, and short beak. It seems to have had the aspect of an ostrich, with a feathered neck and no wings or tail. The feet of the *Dinornis*, with their three large toes, were really enormous. Isolated fragments of its bones suggest very large mammals, rather than birds. The femur and tibia are larger than those of a bear, the tibia alone being about four feet long, and the thickness, in the narrowest part, of the width of a man's hand, while it was more than seven inches in the thickest part. The sternum, on the other hand, was small, convex, and longer than broad. The wings could not have been visible on the outside of the body, for the bones that constitute them are proportionally smaller than those of the *Apteryx*. There was, therefore, a maximum reduction of the wing in this bird.

The *Dinornis* was covered with a rich plumage, and this was doubtless what led to its destruction, women preferring its plumes to all other ornaments. The large number of bones which have been discovered in the alluviums, the caves, and the peat bogs of New Zealand authorize the thought that the island was once inhabited by a considerable number of these birds, which were able easily to repel the attacks of other animals by means of their big feet. But they could stand no chance against Nature's more terrible destroyer—man—who, when seeking the gratification of his taste and fancy, does not hesitate to exterminate whole species. The natives of New Zealand still recall the history of these singular birds; their extermination seems to have occurred about the time the island was

visited by Captain Cook (1767-1778). Moreover, some of the bones collected in later years still had animal matter upon them. Even parts of the windpipe have been discovered, mixed with charcoal, and evidences of cooking have been found.

A near relative of the *Dinornis*, which the Maoris regard as extinct, is the *Notornis*, of which only four living specimens have been found since 1842, the last one having been captured in the latter part of 1898.

The eggs of the *Dinornis* were very large, having a capacity of about a gallon and being equivalent to eighty hen's eggs. Still larger eggs than these, however, are known. In 1851 Isidore Geoffroy Saint-Hilaire exhibited, in the French Academy of Sciences, eggs of a bird coming from Madagascar that had a capacity of two gallons. Some specimens of these eggs may be seen in the galleries of the Paris Museum, and still larger eggs have been found. The museum in London has one with a capacity exceeding eleven quarts, or equivalent to two hundred and twenty hen's eggs, or more than seventy thousand humming-birds' eggs. It was thought at first that the bird which laid these gigantic eggs was still living, for natives of Madagascar spoke of having seen a bird of colossal size that could throw down an ox and make a meal of it. Such, however, were not the ways of the bird called the *Epiornis*, which had no talons or wings, and fed on vegetable substances. The description by the celebrated traveler Marco Polo of a great flying bird of prey, called a roc, has no reference to the *Epiornis*. M. Grandidier has demonstrated that this bird no longer exists in Madagascar, and that, if man ever knew it, the stories with marvelous details which the savages hand down from generation to generation make no mention of it. We owe to M. Grandidier, M. Milne-Edwards, and Major Forsyth what is known of the history of this large wingless bird, which resembles the *Dinornis* in several points. If its size was proportioned to that of its eggs it should have been twice as large as the *Dinornis*. It was not, however, but constituted a family represented by very diverse forms and of variable size, though never much exceeding eleven feet. The head was similar in appearance to that of the *Dinornis*, but the surface of the fore-

head was furrowed with wrinkles and cavities, indicating the presence of a crest of large feathers. A curious peculiarity was the opening of the Eustachian tube directly on the exterior. The cervical vertebræ are very numerous, while the sternum is much reduced. It is a flat bone, broad but very short, especially in the median part. The wing also has suffered a great regression, for it comprises only a thin, short rod, the humerus, and a small osseous mass representing all the other bones of the wing stuck together. The *Epiornis* had no wings externally visible. The bones of the feet were, on the other hand, of considerable size, and indicate that the bird that possessed them was larger than the *Dinornis*.

The *Epiornis*, according to M. Milne-Edwards, frequented the borders of waters, keeping among the reeds along lakes and rivers, for its bones are found associated with those of turtles, crocodiles, and a small hippopotamus. It most probably nested in the low plains around lakes.

Just as the *Apteryx* among birds, and the bison and the beaver among mammals, so the *Dinornis* and the *Epiornis* have been destroyed as man has extended his abode and his domination.

When we regard the fauna of Madagascar and of New Zealand we are struck by the great resemblance between them, from the points of view of their recent and ancient vertebrate fauna. These resemblances suggest the past existence of relations between these two lands now separated by a wide expanse of sea, and this agrees with geological observations.

EVOLUTION AND NATURE STUDIES

The Cobra and Other Serpents

By G. R. O'REILLY

Corresponding Member of the Royal Zoölogical Society of Ireland

DURING a three years' residence in southern Africa cobras and other snakes were my pets and most intimate companions. They occupied my bedroom; they sunned themselves in my windows; they coiled themselves in my armchair and on my study table, and made themselves quite at home among my book-shelves and bric-a-brac. Baby cobras were born into my hands, and adult cobras accompanied me, coiled in my pocket, whenever I went out to take sly observations, through a binocular glass, of the movements of their brothers and sisters still free among the rocks and bushes of plain or hillside.

Above all his peers in the ophidian kingdom, the royal cobra claimed my chief attention. His beauty, the web of Oriental romance in which his name is intertwined, and the dreadful destruction of human life with which he is credited, make him to all of us an exceedingly interesting animal. As man alone stands up and walks erect, the acknowledged king among living things, so it is only the cobra of all the reptile kind that raises himself perpendicularly from the ground and expands his neck as if in fancied pride of his power to dispute with humanity the supremacy over animal life. Year after year, over the whole of Southern Asia, but especially in the Indian Peninsula, a vast multitude of men, women, and children fall victims to his deadly fangs. If each year, within the bounds of British India alone, a town of 10,000 inhabitants were to be utterly depopulated by

a painful form of death, and if this calamity had been constantly recurring, as far back through the centuries as history has record of, who would not be filled with commiseration for a people so afflicted? And yet in that same country this number of human beings is annually carried off by the bite of poisonous serpents, and the world looks for it as a matter of course. Thus the dreaded cholera itself is not a greater destroyer of human life, as it is but an occasional visitant. As the cobra is blamed for nearly all this appalling mortality, we need not seek out further reason for giving him the title of "king of deadly serpents."

Sir Joseph Fayrer, in his magnificent "Thanatophidia of India," gives us copious information regarding his poison, its terrible work among the Indian peoples, and the various methods of counteracting its effects; and more recently our own able inquirer, Dr. Weir Mitchell, has given us its analysis. But as regards the story of cobra life itself, cobra capabilities, and cobra idiosyncrasies, we are still at the mercy of Pliny and his successors. From book to book the old yarns of his fondness for milk and his susceptibility to music are handed down as heirlooms, and will continue to find believers until writing naturalists keep living cobras at their elbows.

Under the general name "cobra" are included several species, differing little in general appearance. They are found all over southern Asia and throughout the entire continent of Africa. In India, *Naja tripudians* is common; in North Africa, *Naja haja*; and in South Africa, *Sepedon hæmachates*. In the other continents no true cobra exists. They are all hooded snakes, and all exceedingly venomous. In color they vary much; some are yellow, some are brown, others black—while in general all are banded more or less distinctly with regular light and dark rings. They are usually about four feet in length and two inches in diameter, but can attain to six feet.

All terrestrial deadly serpents may be divided into two groups—the *Viperidæ*, which have the head covered with small, irregular scales; and the *Elapidæ*, which have it covered with large, regularly disposed plates. Taking the rattlesnake as the representative of the *Viperidæ* and the cobra of the *Elapidæ*, it will

be instructive to note some of the differences between these two famous poisoners. The head in the rattler is broad and flat and the neck very thin; its body increases in diameter toward the middle and gradually tapers off to the tail. In the cobra the head, neck, and body are of the same thickness until the tail commences. In the rattlesnake the eyes have a vertical pupil, like a cat's; in the cobra the pupil is round. In the rattlesnake the fangs are long, well curved, very movable, thin, and with the end of the poison duct coming out almost in the same line with the point of the fang; in the cobra the fang is very short, slightly curved, scarcely movable, strong, and with the end of the poison duct coming out at a large angle with the point. In disposition the rattler is much more sluggish and not nearly so timorous as the cobra. To meet an assailant, the rattlesnake will arrange himself coiled carefully, like a spring, in a horizontal position; while the cobra prepares no coil, but raises himself up on high, perpendicular from the ground. As to the manner of securing their prey, the rattlesnake is like a cat: he lies in wait for it in a suitable locality, and then springs on it unawares, generally waiting till its death struggles have ceased before swallowing it. The cobra, on the contrary, hunts up his victims, pursues them like a dog, and swallows them alive when caught. There is also, as Dr. Weir Mitchell has shown, a marked chemical variance between their poisons.

All these differences are, as a rule, applicable to their respective classes; and it is worthy of mention that in the several points enumerated, excepting as regards the poison arrangements, the *Viperidæ* agree with the true boas and the *Elapidæ* with the colubrine or common harmless snakes. So it will be understood that the cobra is rather a cousin to the black snake than to the rattler.

In searching for his prey, he glides about without anything remarkable in his appearance to denote that he is a cobra; but, when excited by fear or anger, he raises his head and from one-third to one-half of his body perpendicularly from the ground, while the remainder is gathered beneath into a coil of support. At the same time the upper ribs, from the head downward for five or six inches or more, spread themselves out

laterally, carrying the skin with them, thus making of his neck a thin, flattened oval disk four or five inches broad. This wide flatness of the neck is called the "hood," and above it the head appears pointing horizontally to the front. His disposition is so extremely nervous and timid that he will strike at a moving adversary long before he comes near enough to reach him with effect. If you stand before a cobra thus erect and alarmed, and move alternately your left and right hands up and down, he will strike repeatedly to the left and right, following your motions, bringing his head and neck flat on the ground each time, and at every stroke drawing closer to you. In striking thus he hisses audibly and instantly reassumes his erect position, and thus he continues to act as long as danger menaces or a safe avenue of escape does not present itself. This turning to the left and right after one's movements and striking downward is the so-called "dancing," which superficial observers have attributed to the power of music. Even after a slight acquaintance with snake dancing I began to suspect that music had nothing to do with it. Before long I was convinced on the subject.

It happened, I believe, in 1877, that Sir Bartle Frere, Governor of the British dominions in South Africa, when on his way eastward to settle some troubles preceding the outbreak of the war with the southern Kaffirs, paid a visit to my collection at Grahamstown. He arrived unexpectedly and found me on my knees with my sleeves rolled up, washing out my floor, for it was impossible to get a servant to enter the room. Seeing there all the snakes of the country living before him, he was intensely interested, and at once singled out the cobra as an old acquaintance, for he had spent much of his life in India. Many things he told me of Indian snake-charming; but when I made the cobras dance, faint away as if dead, and by a touch return them to life again, he asked in some astonishment how it happened that I did so without the aid of music. I explained the "dancing" as the natural tactics of the cobra in defense and attack, and the fainting and recovery as consequences of an extremely nervous and over-excitable temperament. But my visitor clung to his old opinion, saying that my

belief that they never really danced to the music was opposed to the teachings of natural history and to the experience of every one who had lived in India.

Next day, when the astute Sir Bartle was on his way to the frontier to charm the turbulant chiefs with diplomacy, I invited a flute-player to charm my snakes. I myself went into the room to note results and sat down in my usual place among my pets, leaving the musician outside in the hall, so placed that the snakes could not see him. He played his sweetest tunes. The "Last Rose of Summer," "Annie Laurie," and "Home, Sweet Home" had no effect, so I called to him to play something quick and lively. Accordingly, he gave us "Pop goes the Weasel," "Miss McLeod's Reel," and "The White Cockade"; but never a snake moved. I then invited him inside, but the result was the same, the flute was a failure. Next day I tried the violin. The performer again sat outside, but all his efforts were useless; both quick and slow music were alike lost upon them. On my invitation he came in and sat still a few moments preparatory to commencing afresh. He soon thought himself an Orpheus; for, as he began playing, the cobras stood upon the floor. "Aha!" said he, "see that!" However, believing that they were only alarmed at the quick movements of his arm, I stood over between him and them, thus cutting off their view, whereupon they showed that their fears were quieted by gently lowering themselves to the floor.

On the table was a glass-fronted wooden box in which was a large puff adder. I got the musician to sit close opposite to this and play his loudest, but the snake never showed the slightest sign. Then, at my request, he went round behind the cage and let one end of the violin rest on the top of it. At first he played the higher notes, and the snake showed no sign; but when he touched the deep bass chords the animal swelled himself up and began to blow as if alarmed. Thus, from the instrument resting on the wood of the top, the vibration was conveyed to the whole box, and the snake *felt* it throughout his entire body where he lay in contact with it, in the very same way that I myself *felt* it when I laid my hand upon it.

Many trials were made with other instruments, but always

with the same results, viz., 1. Music from an unseen performer had no effect whatever. 2. If the performer were seen, any noticeable movements of his would alarm the snakes, but in exactly the same way as if he made no noise at all. 3. They gave signs of disturbance when the vibration, especially of bass sounds, was communicated to the material on which they lay.

Thus was proved not only that cobras do *not* dance to music, but that, far from being charmed with the melody, the poor animal is only *frightened* at the movements of the musician, and that the apparent dancing and bowing are only so many half-hearted attempts to strike at the performer or some one moving in his vicinity. Furthermore, I was led to the conclusion that *snakes cannot hear any sound* with sufficient distinctness to determine their acts, unless it is so great as to cause objects in contact with their skin to *vibrate sensibly to the touch*, and that even then they can only be said to feel *the sound's effect.*

At the present moment, as I write, there is on the table before me a glass-fronted box in which are some of our common garter snakes. On the top of this box is placed an alarm clock. Now, when the alarm goes off in this position the garters always move a little, for the vibration is communicated to the wood and can be plainly felt with the finger-tips; but, when the clock is on the cloth-covered table close by and not in contact with the wood on which they lie, they never give a sign of having heard it.

When I lived on the island of Trinidad, I had a large collection of West Indian and South American serpents which it was necessary to feed on animals of many different species. It was always noticeable that neither boa, viper elaps, nor coluber ever gave the slightest heed to the voices of these, while at *sight* of the *moving* prey they manifested very evident signs of recognition. Snakes, as a rule, are very timid, and as I often had visitors at feeding time, it used to be necessary to warn them that any stirring about of arms or legs would be sure to delay the dinner; but no restriction was ever needed to be placed on conversation, except that the turning of the head

was forbidden—each had to talk straight to his front, no matter whom he addressed.

During the past four or five years I have hunted extensively over the woods of northern South America, from the Bay of Panama to the Delta of the Orinoco, often alone, sometimes with others. Now, when I had company it would be frequently necessary to call on their assistance in capturing some of the long, swift-running snakes. If one of these were discovered some distance off, resting close by a fallen tree, it was my method to go round to the other side of the old trunk and come up unseen, often within a yard of him. There I would shout directions to my friends, sometimes at the top of my voice, where to post themselves and where to head him off. This shouting never caused the snake to stir; but should I show the rim of my hat moving up even a hand's breadth over the intervening trunk, he would be off like a race-horse; for the eyes of a serpent, though dull to note form and color, are exceedingly quick to detect motion.

Now, it may be mentioned that snakes have no external ears, their heads being entirely covered, like the rest of the body with a tough and scaly skin. Yet in how far they may be able to detect sound waves in the air, as a general evidence of something unusual, with the delicate tip of the restless bifid tongue, is a subject that requires investigation; but that they can appreciate music in this or any other way is, as has been said above, absolutely untrue. How such an idea as that snakes are fond of music and milk ever gained credence among men calling themselves scientists only shows how few really scientific observers we have.

Men sometimes do strange things for the love of knowledge, and it was this love which caused me to live on such intimate terms with my scaly but graceful and gentle friends. I took them into my house to live with me. This was the best way to know them perfectly; and the more I knew them, the more I knew that they did not know me. I soon found out that neither cobras nor any other serpents can ever become capable of attachment, nor even distinguish one person from another, nor distinguish a man from any large animal, nor even

distinguish a man from a tree stump until he gives evidence of his life by motion.

During my stay in South Africa I had many cobras, all of which I captured myself, except those born in my collection. Now, cobra-hunting is a very dangerous kind of sport, and had I known of its perils otherwise than by experience it is probable that I never would have attempted it. The first two or three I caught safely, and nothing particular occurred to show that there was a special danger in taking *them* which did not equally exist in the capture of other deadly snakes. But I found out that in three important particulars of defense and attack the cobra differs from all his fellow-poisoners:

1. He rarely opens his mouth when striking, but actually gives a deadly blow without biting. 2. He bites deliberately when he is in a state of apparent death from muscular contortion, and will then hang on like a bulldog, the venom flowing all the time into the wounds in which his fangs are buried until he drops off at last from sheer exhaustion. 3. He can squirt the venom from his fangs into a person's eyes, and thus blind him for a time at least.

I had often heard of the "spuugh slang," or *spitting snake*, but looking at the thing from a *too human* point of view—as we are all, unfortunately, overmuch inclined to do when considering animals—I could not understand how a snake, not having fleshy lips and a bulky tongue, could be said *to spit* as we understand the word; and hence could no more believe in spitting snakes than I would in unicorns or fiery dragons. However, the result proved that oftentimes a story which on the face of it seems impossible has, after all, a certain fund of truth lying concealed somewhere at bottom.

One day, being alone in the bush, I saw a cobra banded with black and white. He was in an open glade, gliding about through the herbage, delaying a little perhaps for an opportunity to get at some birds that were chattering and hopping about on the branches of a thorny, yellow-blossomed acacia. The sun was blazing down fiercely on him as, with half-distended hood held close to the ground, he slowly passed through the leaves and flowers. For a few minutes I watched his move-

ments through my binocular glass; but, fearing he might notice me and escape into some hole, I picked up my six-foot hunting stick and rushed toward him, intending to press his head to the ground with it, and then take him by the neck with my hand. He saw me coming, and, like a valiant warrior that knew his power, he faced round and stood erect with expanded hood and quivering tongue ready to receive me. His bright black eyes sparkled with energetic defiance, and every fiber of his being was electrified with excitement. While I was yet ten feet away he struck toward me with such force that the impetus carried him flat to the ground. As I tried to get my stick across his neck he dodged it, and it came instead across the middle of his body. At this moment he was between me and the sun, with about five feet between his face and mine. I looked into his eyes and held him down firmly. His rage seemed redoubled. He leaned backward to make a more vigorous dash at me, and as he struck forward the mouth partially opened, and two tiny streams of venom shot from his fangs as from a syringe, one of them catching me on the face just beneath the eye. Had it gone a little higher up I should have been blinded for months, and perhaps had my sight permanently injured. This unexpected attack made me hasten the capture; so, getting his neck pressed down to the ground with the stick, I soon had him grasped in my hand just behind the head in such a way that he couldn't possibly turn to bite me—which he made every effort to do for some minutes afterward. Taking him home with much satisfaction, I made him thereafter my fellow-lodger. While living in his cage, I observed him many times squirt the venom from his fangs against the glass of its front. Thenceforth my doubts about spitting snakes were removed.

In order to understand how it is that he can eject the venom as high as a person's face—which we never hear of the viperine snakes doing—it is well to consider carefully the approximate difference in the fangs of the cobra and those of the rattler. Snakes of the class *Viperidæ* can, and do under certain circumstances, eject the venom somewhat similarly, but their methods of striking are more deliberate usually, and instead of the first and more copious discharge being thus lost, as is often the

case with the cobra, it is, on the contrary, injected into the veins of enemy or prey. This premature squirting out of the fluid in the cobra is not to be taken as a voluntary act. It has been mentioned above that he is so excitable that he will strike at a moving adversary long before he comes near enough to actually hit his object; and it is in striking thus from a distance that the poison-controlling muscles act as if he really struck something, and the distended gland gives way to the pressure, forcing the contents, which in other circumstances would have been injected into the flesh, to go instead in two thin streams through the air.

In regard to the manner in which the cobra strikes with effect without opening his mouth, it is necessary to state that while the fangs of the rattlesnake and other viperine snakes are laid horizontally back along the upper jaw when the mouth is closed and only erected when the mouth is widely open, it is not so in the cobra; but whether his mouth be open or shut, his fangs are always partially or wholly erect, and not in the true sense of the word reclinable. Now, usually when he strikes at an adversary his mouth does not open as does the rattlesnakes, but he simply hits with his chin the point he aims at, so that, the mouth being still shut and the fangs during the act coming out over and slightly below the lower lip, these protruding fang-points penetrate the skin, while at the same instant the potent venom is squirted with force through these natural hypodermic syringes into the superficial punctures. Hence it is that on the bare legs of the natives this so-called "bite" is usually fatal, while the slight protection of trousers saves the European from danger.

As to the third peculiarity of this snake—viz., the fit of temporary lockjaw into which he is liable to fall and the terribly prolonged and real bite he can give when in that state—the account of an interesting adventure I once had will give a fitting illustration. It was a most wonderful exhibition of reptilian hysterics.

In the midst of a South African summer, when the springs and rivers are dried up, the snakes congregate in unusual numbers around the dams which are built by the colonists to store

up in the ravines for themselves and their cattle the drinking supply afforded during the rains by the mountain torrents. At one of these reservoirs in Currie's Kloof, near Grahamstown, I had secured several fine serpents, and was not surprised therefore when one afternoon, as I was sitting by an upper window, I saw a boy running from that direction toward the house, shouting as loud as he could bawl, "A snake, sir—a monster snake!"

I ran downstairs and found him, breathless and pale with excitement, at the door. The snake, he said, was fully twenty feet long. It had pursued him a little way through the bushes and then disappeared in a hole in the bank. "Aha!" thought I, "this must be the great Natal python I have heard so much about but never seen." With some doubts, nevertheless, about his being twenty feet long—for people usually imagine snakes which scare them to be much bigger than they really are—I took my snake-hunting stick and set off at once to make the capture. On arriving at the pond, which was overhung by poplar trees and nearly dried up, the boy led me across a long stretch of hardened, sunbaked mud to a point in the great earthen dam about twenty feet over from the water's edge, where there was a hole, the mouth of which he had carefully stopped up with a good-sized stone before coming to tell me. This I removed, and as the snake was not there ready to bolt out as I expected, I ran in the stick to dislodge him. This, however, had no effect. So, taking a piece of stout paling wire, I made with it a hook to the end of my snake stick. Running in this arrangement, I managed to catch it in his folds, a proceeding which he resented by slipping it off and by many angry hissings which sounded all the louder from being uttered in the confinement of his subterranean retreat. After several failures he was at last hauled out. "A cobra, by Jove!" said I, as he raised himself up erect with expanded hood on the hard mud expanse between me and the water. As his head when standing thus was fully eighteen inches high, it was no easy matter to press his neck to the ground so as to catch him safely with my hand. Without at all hurting him I made several attempts to get his neck down, and not without some nervousness, for

he might at any moment send a charge of venom into my face. This playing him with the stick to get him into proper position so aroused and alarmed him that at last, overcome by his own excitement, he suddenly collapsed, falling over on his side and lying there motionless, half on his back, with his mouth fixedly open and stiff as if in death. His whole body was rigidly contorted and as unbending as a dried stick. "Ah, you've killed him!" shouted the boy from the top of the dam, whither he had retreated for safety. However, as I had seen this manifestation before, I knew that it was only an hysterical fit. Warning the lad not to approach, I picked up the apparently lifeless snake by the tail-tip and flung him off from me to a distance of five or six feet. As soon as he touched the ground all his life was active again. Up he stood instantly with expanded hood as before, the black eyes glistening angrily and the forked tongue running out quiveringly from the closed mouth as if daring me to approach. A slight touch with the stick on the neck caused him to fall down in a second fit similar to that from which he had just recovered. There he lay again, to all appearance dead, with every muscle rigid and his jaws fixed in a partial gape as if sudden dissolution had prevented their closing. Seeing in this an opportunity of giving the boy a lesson against the danger of meddling with seemingly dead cobras, I called him down to my side. "Do you think that snake is dead?" said I.

"Yes," he replied, "I believe he is surely dead now; you must have given him his death wound getting him out of the hole."

"Well, my boy, I'll show you whether he is dead or not; and from what you will see, take warning that a bite from an apparently dead cobra like this is a thousand times worse than if he were to strike you perchance in the usual way as you pass through the bush."

So saying, I put the end of the stick into the stiff, gaping jaws. Instantly they closed on it like a vise until the fangs were buried in the wood. Then, lifting him up till his tail swung clear of the ground, I bade the boy count the time by his watch, to see how long he would retain his bulldog-like

grip. The body was gathered into unbending curves; but, as the minutes went by, these straightened out, commencing at the tail and advancing gradually upward to within three inches of the head. At last this too became limber, the jaws unloosened, and he dropped to the ground as the boy exclaimed: "Well, I'll be blamed! that bulldog snake held on for eight minutes and a half." As he lay now exhausted on the ground he put out his tongue at intervals, but never otherwise moved until I attempted to put the stick across his neck preparatory to taking him, when he stood up for fight as fresh as ever. However, I was nimble with the stick, and by its aid got my fingers round his throat just as he went into his third fit, and held his deadly jaws open again ready to close upon anything they should chance upon. Thus open-mouthed he remained as I carried him homeward, but recovered from his fit as he was placed in his cage.

The fears of the boy had quadrupled the animal's size, but still for a cobra he was large, being considerably over four feet in length. Having him now at home to practice on, I soon learned how to throw him into this state of temporary lockjaw, and instantly restore him again at pleasure. And besides this, I became certain that the ordinary wounds made by a cobra are nothing compared with his terrible bite when in this strange condition.

Among my collection I had at first six cobras. They used to eat frogs and toads, pursuing them around the room as a dog would a rat, seizing them by whatever part they could catch hold of, and swallowing them down whole and alive. After a time the family increased, for one Saturday night an old lady cobra surprised me by depositing on the dressing-table a number of living young ones about as thick as a large cigarette and seven inches long. In these little snakelings the instinct of self-defense was born; for, before they were a minute old, they stood up erect, ready to strike like their parents. They were provided with poison, too, but could not expand their hoods till they were a week older.

Dear, pretty, little venomous babies!—infant criminals of the reptile kind—they had no more knowledge of nor affection

for their mamma than if she were an old tree-root or something else inanimate lying in their way and troublesome to be climbed over. Nor would the mother take the slightest notice of her interesting family. Indeed, some of them she never saw at all. Most probably she didn't know that they were any relations of hers, or she would have shown them some little attention.

EVOLUTION AND NATURE STUDIES

The Serpentlike Sea-Saurians

By WILLIAM H. BALLOU

IN the latter part of the Mesozoic Age there was a great inland ocean, spreading over a large part of the present continent. The lands then above water were covered with a flora peculiar to the times, and were inhabited by some of the animals which later distinguished the Cenozoic age. In the seas were reptiles, fishes, and turtles of gigantic proportions, armed for offense or defense. There were also oyster-like bivalves, with enormous shells, three or four feet in diameter, the meat of which would have fed many people. In time, this great ocean, swarming with vigorous life, disappeared. Mountain ranges and plains gradually arose, casting forth the waters and leaving the monsters to die and bleach in Tertiary suns. As the waters remaining divided into smaller tracts, they gradually lost their saline stability. The stronger monsters gorged on the weaker tribes, until they, too, stranded on rising sand bars, or lost vitality and perished as the waters freshened. In imagination, we can picture the strongest, bereft of their food supply at last, and floundering in the shallow pools until all remaining mired or starved. It would be interesting to know how much of the great Cretaceous ocean forms a part, if any, of the vast oceans of to-day. If any part so survived, what became of the saurians carried forth into new ocean areas? Were they beaten on jagged rocks by powerful currents and destroyed, or did some of them escape only to perish in after ages? Water, as a rule, seeks its level; sometimes it is evaporated. If the Cretaceous ocean merely drained off into other areas before

rising lands, it is perhaps not unreasonable to suppose that the descendants of some of the saurians might have survived in the Atlantic or Pacific as they had existed in the Mesozoic Age. We can therefore only assume that the Cretaceous seas evaporated or gradually freshened until all the life they contained became extinct.

During the past twenty-five years explorers have collected tons of skeletons of the stranded sea-serpents, or better, perhaps, serpent-like sea-saurians. A sensational world has ever been on the lookout for sea-serpents. It is possible that such tendencies are inherited from a very remote ancestor, a primeval, man-like animal, whose curiosity was aroused by glimpses of some surviving pythonomorph.

Almost everywhere on the expanse of the Cretaceous ocean might have been seen the snake-like forms of the elasmosaurs, the heads arrow-shaped, upheld by swan-like necks, rising from ten to twenty feet above the surface and scanning the sea or air for prey or enemies. The prey located below, they dived; the enemy seen approaching, they swam away with incredible speed. A flock of them must have resembled the shipping of a harbor with tall masts yellowing in the sunlight. At the base of the long necks were elephantine bodies, and, behind, long, tapering tails. Forward and behind were two sets of paddles, perhaps terminating with webbed digits. With the forward paddles Cope thought that they might have seized prey; with all four paddles they swam. From thirty to sixty feet in length, they were well adapted to the deepest waters and to breast the waves of the seas. Like swans and Floridian snake-birds, they plunged their necks downward for prey, the body perhaps remaining on the surface as an anchor. Carnivorous, the elasmosaur ate what it could seize, and to-day, with its bones, are found the bones of its victims, usually fishes. Somewhat similar were the cimoliosaurs, even longer-necked at times, but with shorter and more powerful tails. Their paddles were long, and as swimmers they must have had few equals in speed. Smooth siliceous pebbles to the amount of a peck or two have been found in numerous instances associated with the remains of plesiosaurs of various kinds. They evi-

dently formed a part of the contents of their stomachs, but their use is not clear. But the real rulers of the Cretaceous ocean were the pythonomorphs, or mosasaurs, more like the typical serpents of to-day, and more entitled to be called sea-serpents.

The mosasaurs were more elongated and graceful in form. Their heads were large, flat, and conical, with the eyes directed laterally. The tails were long. They had fore and aft paddles with webbed digits, attached to the body with wide peduncles. With paddles and flattened tails they swam with ease and speed. Like snakes, they had four rows of formidable teeth on the roof of the mouth, not for mastication, but for seizing prey and holding it. Like snakes, they swallowed their prey entire, but, unlike snakes, they had not elastic throats. The jaw was, however, so articulated, jointed so far back between the ear and chin, ball-and-socket fashion, that the immense opening made up for the lack of expansibility of throat. The ends of the jaws were bound by flexible ligaments, permitting the passage of large fish or other prey. The mouth of the gullet was prolonged forward while swallowing, evidently being loose and baggy. The same habit pushed forward the glottis, or opening of the windpipe in front of the gullet. Like a serpent, the mosasaur hissed, owing to these formations. The tongue was long and forked, and when at rest was inclosed in a sheath beneath the windpipe and thrown out when the jaws were in motion. And thus, too, are the nearest living forms.

The mosasaurs attained great length, reaching from ten to fifty feet. They had long, projecting muzzles, somewhat like that of the blunt-nosed sturgeon of to-day, although the branches of the lower jaw were correspondingly massive. With such ramlike jaws the mosasaur possessed terrible powers of collision. They were scaled animals, and fragments of their hides and scales have been found in good condition of preservation.

The first mosasaur discovered was found by Major Drouin in 1776, on the banks of the river Meuse, near Maestricht, Germany. On this specimen was founded the genus *Mosasaurus*, given it by Conybeare in 1822, although the skeleton was previously described by Cuvier in 1808. The inter-

esting history of the specimen, which created a profound sensation in the world of learning and became mixed up in the history of nations, is herewith reduced from Owen. The skull was founded in the quarries of St. Peter's Mount by M. Faujas Saint-Fond, Commissary for Sciences of the French Army of the North. In one of the galleries or subterraneous quarries in which the cretaceous stone of St. Peter's Mount was worked, about five hundred paces from the entrance and ninety feet below the surface, the quarrymen exposed part of the skull in a block of the stone which they were engaged in detaching. On this discovery they suspended work and went to inform Dr. Hofmann, surgeon of the forces of Maestricht, who for some years had been collecting fossils at this quarry, remunerating liberally the workmen for the discovery and preservation of them. Dr. Hofmann arrived at the spot and saw, with extreme pleasure, the indications of a magnificent specimen. He directed the operations of the men so that they worked out the block without injury to the skeleton, and he then with his own hands cleared away, by degrees, the yielding matrix, exposing the extraordinary jaws and teeth, which have been the subject of so many drawings, descriptions, and discussions. This fine specimen, which Hofmann had transported with so much satisfaction to his collection, soon, however, became a source of chagrin to him. Dr. Goddin, one of the canons of Maestricht, who owned the surface of the soil beneath which was the quarry whence the fossil had been obtained, when the fame of the specimen reached his ears, pleaded certain feudal rights in support of his claim to it. Hofmann resisted, and the canon went to law. The whole chapter supported their reverend brother, and the decree ultimately went against the poor surgeon, who lost both his specimen and his money, for he was made to pay the costs of the action. The Canon Goddin, leaving all remorse to the judges who had pronounced the iniquitous sentence, became the happy and contented possessor of this unique example of its kind. But justice, though tardy, comes at last. When the town was bombarded by the French, directions were given to spare the suburb where the famous fossil reposed. After the capitulation, the grenadiers discovered, seized, and bore off

the specimen in triumph to the commissarial residence. The excellent soldiers always knew how to appreciate and respect the monuments of art and science. The mosasaur was transplanted and still remains in the Museum of the Garden of Plants, Paris, and is the subject of more literature than any extinct animal.

Remains of the mosasaurs were first discovered in England in 1833, at Lewes. In America, mosasaurs were first found in the cretaceous beds at Great Bend, Missouri, about the year 1820, by Major O'Fallon, Indian agent. He found a fine specimen, and took it to his home in St. Louis. Dr. Goldfuss first described it in 1843, with accompanying plates, the skeleton having been taken to Germany by Prince Maximilian. He defined the parietal and jugal arches, pterygoids and vomers, the position of the quadrate, and the presence of the sclerotic plates. Since that time our knowledge of the mosasaurs has been largely increased by the explorations and efforts of Cope, Marsh, Dollo, Owen, Leidy, Williston, Baur, Merriam, Gaudry, Gervais, and others. Cope, perhaps, defined the largest number of species. March defined the stapes, columella, transverse and hyoid, and the presence of hind limbs. Dollo has materially increased the data of mosasaurs and has added four new genera. Baur gave the first complete description of the skull of a species of *Platecarpus*. Williston and Case first described the vertebral column and extremities and the general form of mosasaurs. The former has contributed most to our knowledge of mosasaurs in the Kansas Cretaceous, and made the first correct restoration, which is made one of the bases of this paper.

Professor S. W. Williston, University of Kansas, because of his perfected restorations and wide studies of the sea-serpent-like saurians, the mosasaurs and other marine saurians, must rank as the highest authority. It is largely on his material that it is possible to present something like a complete view of the gigantic monsters that swam the Cretaceous seas and gave origin to our notions of mythical sea-serpents. Kansas is the great center of the Cretaceous time of occupation, and it is within its borders that the largest number of species and genera of sea-serpents have been discovered. It is natural, perhaps,

that, living in the vicinity of the most prolific Cretaceous remains, Professor Williston should be better able than scientists more remote to complete our knowledge of marine saurians.

There are three groups of the serpentlike sea-saurians—the ichthyosaurs, plesiosaurs, and mosasaurs. Of the mosasaurs, Kansas has produced the largest number of species, twelve of which have been satisfactorily described. New Jersey, Alabama, Carolina, and Mississippi have perhaps ten valid species. Dakota has favored us with three species. It is estimated that of fifty species attributed to North America, about twenty-five or thirty will be distinguished as distinct. It is expected that in the Fort Pierre formation of the Dakota region other species will be found, as it has been but imperfectly explored. Europe has about a dozen species, and New Zealand several more. Probably only about forty species of twice as many alleged to have been discovered in the world will stand the test of critical examination.

Of plesiosaurs, America has produced about ten and the Old World many more species that will stand. Many species of ichthyosaurs are recorded from Europe, India, Africa, Australia, New Zealand, and the arctic regions, and one or two in America, the toothless *Baptanodon* from the Jurassic of Wyoming being the type. All three groups had paddles with webbed digits, but none had claws. Williston thinks that the ancestors of the mosasaurs were land lizards. Dollo thinks that the ancestors were the peculiar group of lizards which appeared in the commencement of the Cretaceous known as *Dolichosauria*. Baur would derive the mosasaurs from even more specialized lizards, and believes that their relationship is very close to the monitors of the present day.

The ichthyosaurs are thought by Cope to be derived from *Homœosaurus* (beakless lizards) of the Jurassic; and these from the *Palæohatteria* (ancient hatteria), a rhynchocephalian (snout-head) which flourished as early as Permian times; and these from the *Labitosaurus*, an ancestor below the Carboniferous in the Palæozoic Age; from which also sprang the lizardlike saurians, the dimetrodons (*Otocœlius*), which gave origin to the turtles (*Testudinata*). Some members of the group to which

the plesiosaurs belong were land animals, and hence the origin of the whole group is clearly from land species. It is not now presumed that the marine saurians had much power of progression on land, but they may have climbed on to the beaches to lay their eggs. It is further presumed by Morris that in later times the eggs of saurians were devoured by other animals, contributing to the extinction of all saurians.

Three species of representative genera of Kansas mosasaurs have been restored by Williston from material in the University of Kansas.

Clidastes velox (Marsh) is a typical mosasaur, the perfected skeleton of which is twelve feet in length. *Pumilus*, of the same genus, is given as six feet in length, which would rank it as perhaps the smallest mosasaurian. The clidastes of Kansas had short, powerful propelling tails, which would indicate a lesser speed than that of their longer-tailed contemporaries. The clidastes had small hind limbs, showing further deficiency in speed. The animals were slender, with short heads. The vertebræ were firm, closely articulated with the best system of interlocking of any of the mosasaurs. The limbs were flexible and strong, with closely articulating bones and fully developed tarsus and carpus. The aggregate of these characters indicates the most snake-like form and method of progression through water of all the mosasaurs. The genus *Clidastes* was founded by Cope in 1869, but may ultimately give way to the genus *Mosasaurus* of Conybeare. Cope's views of clidastes conclude that the animals were not as large as those of the genus *Liodon* (Owen), but more elegant and flexible, with an additional pair of articulations at either end of each vertebra—the zygosphenes—to prevent dislocation by contortions. A larger and still more elegant species was *Clidastes tortor* (Cope), with lithe movements which enabled it to capture fish by means of its knife-shaped teeth, which were very numerous. Tortor was very slender, with a long and lance-shaped head. It was upward of twenty feet in length, with a head two feet and a half long, the vertebral column elongate and the head narrow and pointed.

The second-type mosasaur perfected by Williston is *Plate-*

carpus coryphæus (Cope). Its special characteristics are a short muzzle, slender vertebræ, and an imperfect interlocking zygosphene. The hind paddles are smaller than those forward, but thought to have been more powerful propelling functions than those possessed by other genera. A type skeleton measures fourteen feet, and may have been a young animal. The teeth were very curved and pointed, and formed effective weapons. The neural spines, not closely connected, indicate flexibility. The general characters suggest a powerful predaceous sea-serpent. The genus was founded by Cope in 1869; it has a wide distribution, and seven or eight species belong to it.

Tylosaurus proriger (Cope) is the third of Williston's type Kansas specimens perfected in restoration. It is considered the most specialized of the mosasaurs. The skeleton in hand is twenty-three feet in length, and shows a wholly cartilaginous carpus and tarsus, more elongated digits, and a greater number of phalanges than possessed by any other genus, the result of long aquatic habits. The hind paddles are the largest, and the fifth digit has undergone but little reduction, indicating characters of a very primitive rank. The vertebræ are more flexible than in other genera, but they are relatively smaller and not at all strong. The skull is more elongated anteriorly. In the same genus was a much larger species, *T. dyspelor* (Cope), which was one of the most formidable of the mosasaurs. Another perfected sea-serpent of terrible powers was *Mosasaurus horridus* (Williston), which had a ram nose, and evidently battered its foes when it could get at them. Williston's perfect skull from Dakota enabled him to correct many errors in vogue. The new genus *Brachysaurus*, formed by Williston, contains one species defined by him—*Overtoni*, from Dakota. It had a stout, very broad head, stout jaws and teeth, and stout, broad paddles. In appearance it suggests a terrible fighter, unadapted to rapid pursuit or flight.

Williston thinks that the food of the sea-serpent-like saurians must have consisted of fishes of moderate size, with occasional victims of their own kind. He says: "While the flexibility and loose union of the jaws undoubtedly permitted animals of considerable size to be swallowed, the structure of the thoracic

girdle would not have permitted any such feats of deglutition of which the python and boa are capable. The animals must have been practically helpless on land. They were not sufficiently serpentine to move about without the aid of limbs, and these were not at all fitted for land locomotion. They lived in open seas, often remote from the shores. Their pugnacity is amply indicated by the many scars and injuries they received, probably from others of their own kind."

Over the water were the flying saurians of formidable proportions, and which may have been both pursued and pursuer, according to size of mosasaur and pterosaur. The pterosaur had a wing expanse of eighteen to nineteen feet, as instanced in *Ornithostoma umbrosum* (Cope), the largest in size, and *O. ingens* (Marsh). The pterosaurs flew with leathery wings over the waves, plunging to seize unwary fishes or perhaps to be seized by mosasaurs, or soaring at a safe distance while watching the combats of swimming saurians. At nightfall they trooped along the shores, at last to suspend themselves to the cliffs by the claws of their wing limbs.

Prof. O. C. Marsh, of Yale College, was the first naturalist to discover sufficient of the missing parts of skeletons to determine that marine saurians propelled themselves with paddles rather than flippers. As to the scales and skin found perfectly preserved by Snow, they do not differ materially from those of the Old World lizards, the monitors, existing to-day. The paddles, skin, and scales are very delicate functions, and it is remarkable that they should have been preserved through millions of years. Williston says of the paddles: "The specimen figured by Chancellor F. H. Snow, of the University of Kansas, has been thoroughly cleaned from the matrix, enabling an accurate drawing to be made, also a photographic reproduction as it lies on a chalk slab. The parts concealed beneath the ribs and vertebræ have been carefully laid bare from the opposite side and their position shown. The position of the paddle is a natural one, and the fact is of interest as showing the general expansion and curvature of the digits." The limb is very flexible, with considerable space between the bones, which were but partly filled out with cartilage, and must have had very free

articulations. The remains of the skin were found between the bones, indicating a thin, pliable membrane, and extending fully between the fingers to their tips. Small scute-like scales extended as far as the metacarpals. The fifth finger is long. The paddles are slenderer, more flexible, and relatively longer than in other genera, which, with other characteristics, would show that *Tylosaurus* was the least lizard-like of the *Pythonomorpha* (Cope.) As to the structure of the hind paddle, it is of interest in having five functional toes, although Williston thinks that the fifth toe was undergoing reduction, and that the first toe was not as long as in the front paddle. He concedes five toes to the hind paddle of *Platecarpus* (Cope), but doubts, in the absence of a complete skeleton, if *Clidastes* had more than four functional toes, as in *Mosasaurus*. Upon this character, together with the absence of a sternum, he has established two families, *Tylosauridæ* and *Mosasauridæ* and the two typical genera, representing the extremes of development of this order of reptiles.

In this connection it is interesting to note the views of certain scientific men of the times in which these gigantic sea-serpents existed.

The views of Prof. Frank C. Baker, curator of the Chicago Academy of Sciences, follow: "At the time the great sea-lizards lived, North America was shaped something like the following: It included all of Northeastern Canada and Nova Scotia; the shore line was the same as at present as far as New York, where it was deflected to the southwest and went through the western part of New Jersey, Delaware and Maryland, and then went directly across the middle of Alabama, north again to the mouth of the Ohio River where it meets the Mississippi River, then north into Iowa, and finally north and northwest across the United States and British America. Herein existed a great inland sea in which the sea-lizards lived. The past history of the world tells us that thousands of animals of gigantic size lived in the ancient seas. In old Jurassic and Cretaceous times we had such queer combinations as *Ichthyosaurus* (or fish lizard) and *Plesiosaurus*. Not only were reptiles found in the water; they flew about in air. The latter were represented by

the *Rhamphorynchus*, a bird-like reptile which had wings like a bat, teeth like an alligator, and the tail of a lizard. In the Connecticut Valley we find the footprints of huge reptiles in the red sandstones whose feet measured from those of a few inches in length to the footprints of the gigantic *Otozoum*, which measured twenty-two inches in length, having a step of some five feet."

An immense amount of literature has been printed on the subject of the Cretaceous formation and its inhabitants. Very recently there have been immense advances made in the restoration of species existing in Cretaceous times. This article, therefore, is in the nature of scientific news, and a separation of facts from a mass of errors. In looking over the works of others, one is impressed by the many mistakes made by specialists, owing to imperfect skeletons and collections. A careful study of these errors has been made in the light of the latest skeletons reconstructed and the latest discoveries made.

The Kansas University, in securing three perfect type specimens of three genera of mosasaurs, presents three important items of scientific news. These skeletons teach us the errors and pitfalls into which specialists have fallen who lacked certain parts of the skeletons and filled out the gaps by aid of the imagination. Only recently the country was startled by the alleged discovery of the skeleton of a supposed reptile, having a length of two hundred and fifty feet. The newspapers gave startling pictures of the supposed appearance of this reptile while on earth. Professor Williston naturally wanted to see this gigantic animal, the largest ever discovered. On examination of its bones he saw at once that it was a whale. It can safely be asserted that no animal ever attained a length of two hundred and fifty feet. Perhaps as serious errors as this may be found in many of our text-books and monographs, due, of course, to former incomplete skeletons. The appearances of the skulls, the jaws, and the teeth have been painfully distorted in like publications and on charts in class rooms, and demand a thorough overhauling before our youth are further taught errors. With late complete discoveries, we have now exact appearances of the functions of the heads from which we can

derive correct views. It was formerly thought that the eyes of the mosasaurs were directed upwardly; to-day it is known that they were directed laterally, as in living lizards. It has been supposed that mosasaurs attained a length of one hundred feet; no skeleton has been found which would show a length of more than fifty feet. The great majority of skeletons taken range from sixteen to twenty feet in length. It was formerly supposed that mosasaurs had the powers of running, springing, and climbing on land; it is now known that they were wholly confined to salt water, and merely climbed the beaches in order to lay eggs. It is not an easy step from mosasaurs to modern snakes; it is an utter impossibility. Professor Marsh formerly thought, and it has been taught in the class rooms, that the bodies of mosasaurs had bony scales; they had skins, and were scaled throughout like modern lizards and snakes. The *Rhamphorynchus* has been held up to us as a "lizard-like bird"; it was no more like a bird than is a bat; it was a bird-like reptile. These suggestions certainly point to the necessity of a revision of the text-books and charts in use in class rooms, which in many instances should become obsolete because of perfected restorations.

Specialists regard the marine saurians as having existed some millions of years ago. They conclude that these animals had at least a million years of existence in various forms. While it may be venturing into the domain of the encyclopædia to state the causes of these conclusions, a word here may not be out of place. The Cretaceous formation, in which the marine saurians are found, is of chalk, green sands, etc., and ranges in thickness from 10,000 to 20,000 feet or more It existed in the last part of the Mesozoic realm. From the thickness and position in geological strata scientists deduce its age and place in Nature. As the remains of marine saurians are found only in the Cretaceous deposits, specialists speak of them as existing several million years ago. At that time were numerous fishes, birds, reptiles, and plants.

BIOGRAPHIES

JEAN LOUIS RUDOLPHE AGASSIZ, naturalist, was born in Motier, Switzerland, May 28, 1807. In boyhood his interest in books was small, but his fondness for objects of natural history and domestic pets correspondingly large. He studied for four years at the college for boys at Bienne, and here, aside from his studies, made his first collection of fishes. He progressed to the college at Lausanne, thence to the medical school at Zurich, from which institution he went to Heidelberg, where he studied botany and anatomy, and, in 1827, went to Munich, where he lodged in the house of Dr. Johann Döllinger, who encouraged him in his predilection for zoölogy. His work on "Fossil Fishes," published in 1830, gave him a place among European scientists, and the next year he went to Paris and enlisted the interest of Cuvier, with whom he stayed until the latter's death. He sided with Cuvier in his opposition to the development theory advanced by Geoffrey. Through the interest of Humboldt, he obtained the chair of natural history in the college at Neufchâtel in 1832. The next year he published the first of his five quarto volumes, "Recherches sur les Poissons Fossiles," the last volume coming ten years later. He made excursions to the Jura and the Alps to study glaciers, had a station built on the center of the Aar glacier twelve miles from any human abode, and, in 1840, published "Études sur les Glaciers," followed in 1847 by his "Système Glaciers." Investigations of fossil remains occupied him until 1846, when he visited America to study its natural history and geology. His lectures in the large eastern cities gave him a great popularity; the richness of the American field for a naturalist decided him to remain here, and, in 1848, he accepted the chair of zoölogy and botany at the Lawrence Scientific School of Harvard University. Though invited to return to Europe and occupy chairs in various universities, he remained in his adopted country, being instrumental in the founding of the Museum of Comparative Zoölogy at Harvard, known more popularly as the Agassiz Museum, and the Andersen School of Natural History on Buzzard's Bay. Among his works written in English are "Principles of Zoölogy," "The Structure of Animal Life," and "Scientific Results of a Journey in Brazil." He died in Cambridge, December 14, 1873.

RAY STANNARD BAKER, magazine writer and editor, was born in Lansing, Mich., April 17, 1870. In 1892 he began writing stories for the "Youth's Companion" and articles for "The Outlook," "Independent," and "Harpers' Weekly." In 1898 he became a member of the staff of the S. S. McClure Company, being occupied at times on both newspaper syndicate and magazine.

In 1899 he went to Cuba, in 1900 to Europe in the interests of the McClure establishments, and in 1901 to Arizona, New Mexico, and California for the Century Company. He published the "Boys' Book of Inventions" in 1899, "Our New Prosperity" in 1900, and "Seen in Germany" in 1901.

Sir Robert Ball, English astronomer, was born in Dublin, July 1, 1840. He was appointed Lord Ross's astronomer in 1865, and, in 1873, became Professor of Mathematics and Mechanics at the Royal Irish College of Science. At present he is Lowndean Professor of Astronomy and Geometry, Cambridge. He is the author of "The Story of the Heavens," "Starland," etc., and is well known in America as a lecturer on astronomical subjects.

Pierre Eugène Marcellin Berthelot, a French chemist, was born in Paris, October 25. 1827. In 1859 he became Professor of Organic Chemistry in the École de Pharmacie, and in 1865 assumed the same position in the Collège de France. In 1876 he was made Inspector-General of Higher Education, and in 1886 Minister of Public Instruction. He won great distinction by the synthesis of organic compounds formerly supposed to result only from the action of vital forces. He published "La Synthèse Chimique" and many other scientific works.

Frank Michler Chapman, zoölogist, was born June 12, 1864, in Englewood, New Jersey. In 1887 he was appointed Assistant-Curator of Vertebrate Zoölogy in the American Museum of Natural History, which position he continues to hold. He is President of the Linnæan Society of New York, and has been a member of the American Ornithologists' Union since 1888. He has written "Handbook of Birds of Eastern North America," "Bird-Life," and "Bird Studies with a Camera."

Henry Drummond, Scotch scientist and religious writer, was born at Stirling, Scotland, on August 17, 1851. He acquired his education at the universities of Edinburgh and Tübingen, and at the Free Church Divinity Hall, where he pursued the courses in theology. After being ordained he was appointed to a mission chapel at Malta; but he abandoned the work of the ministry, and, in 1887, became Professor of Natural Science in the Free Church College, Glasgow. The intervals between his professorial occupations were spent in travel, with scientific investigations as a partial objective. He visited South Africa and the Rocky Mountains with this end in view, and made lecture tours in Australia, Canada, and the United States. In 1883 he published "Natural Law in the Spiritual World," which was followed later by "The Ascent of Man," two works in which he has endeavored to bring modern scientific methods to the discussion of the phenomena of the immaterial universe. In 1888 he published his book on "Tropical Africa." Besides the foregoing he is the author of "Pax Vobiscum," and "The Greatest Thing in the World," published in 1890, and "The Programme of Christianity," in 1892. He died in Tunbridge Wells, England, March 11, 1897.

MICHAEL FARADAY, chemist and physicist, was born in Newington Butts, September 22, 1791. His father was a poor blacksmith with a large family. Michael was early apprenticed to a bookbinder and stationer, with whom he remained eight years. As a boy he was interested in science and made experiments. In 1812, after attending lectures given by Sir Humphrey Davy at the Royal Institution, he sent his notes to the lecturer and sought his aid to escape from trade. Davy engaged him as assistant in the laboratory at the Royal Institution, and in 1813 took him on his journey in France, Switzerland, Italy and the Tyrol. On their return, Faraday reëntered the services of the Royal Institution. In 1825 he was elected a Fellow of the Royal Society and in 1830 began to contribute to it accounts of his discoveries in magnetism and electricity. In 1835 he was appointed Professor of Chemistry to the Royal Institution, where he delivered the annual lectures until his death, His investigations tended to establish the theory that electricity, light, and heat are modifications of the same force and convertible into one another. In 1835 his services obtained from the State a pension of £300 a year, and in 1846 the Rumford and Royal Medals were awarded him for the discovery of diamagnetism. His volumes of "Experimental Researches" were published at intervals from 1839 to 1859. His nature was deeply religious and his manner simple and unaffected. It was his custom to give lectures at the Royal Institution at Christmas to an audience of children. The last of such courses was on "The Chemical History of a Candle," in 1861. In 1858 the Queen assigned him a residence at Hampton Court, where he died August 25, 1867.

CAMILLE FLAMMARION, French astronomer, was born in Montigny-le-Roi, February 25, 1842. He is the author of popular works on astronomy, many of which have been translated into English. Among them are "The Stars," "The World Before the Creation," "Uranus," "Comets," and "Popular Astronomy."

AUSTIN FLINT, American physician, writer on medicine, was born in Petersham, Mass, in 1812. He graduated with the degree of M.D. at Harvard in 1833. He was one of the founders of the Buffalo, N. Y., Medical College in 1847, and in 1861 was appointed Professor of the Principles and Practice of Medicine in Bellevue College Hospital, New York, and Professor of Pathology and Practical Medicine in the Long Island College Hospital. He published "Practical Treatise on Diseases of the Heart," "The Practice of Medicine," "Auscultation and Percussion," and "Clinical Medicine."

AGNES GIBERNE, English author, was born at Ahmednugger, India. She began to write at seven years of age, her first story for children being published when she was only seventeen. Her most popular work has been her scientific writings, "Sun, Moon and Stars," "The Starry Skies," "Among the Stars," "The Ocean of Air," "The World's Foundations," "Radiant Suns," etc. She lives at Eastbourne, England.

ELISHA GRAY, electrician and inventor, was born near Barnesville, Ohio, August 2, 1835. Early in life he learned blacksmithing, carpentry and boatbuilding, from which he turned to pursue special studies in physical science at Oberlin College, where he constructed the apparatus used in the class room for experiments, at the same time supporting himself by working at his trade. In 1867 he invented a self-adjusting telegraph relay, and in 1869 established a manufactory of electrical apparatus at Cleveland, Ohio. He perfected the typewriting telegraph, the telegraph repeater, telegraphic switch, annunciator, etc. In 1872 he organized the Western Electric Manufacturing Company, but retired from it in 1874. In 1876 he invented the speaking telephone and, in the dozen years following, took out more than fifty patents on details of telephony. In 1893 he invented the telautograph. He established the Gray Electric Company at Highland Park, Ill., and, in 1893, organized the Congress of Electricians in connection with the World's Columbian Exposition, and was made its chairman. During the last year of his life he worked upon a system of submarine signaling. He was the author of "Experimental Researches in Electro-Harmonic Telegraphy and Telephony," and also of "Nature's Miracles." He died in Newtonville, Mass., December 31, 1900.

THOMAS HENRY HUXLEY, English biologist, was born at Ealing, Middlesex, England, May 4, 1825. He studied medicine at Charing Cross Hospital, and in 1846–'50 went as Assistant-Surgeon of H.M.S. "Rattlesnake," which made an expedition to explore the passage between the Barrier Reef and the Australian coast. His studies of marine life were afterwards utilized in the preparation of many scientific papers that brought him high honors. He became a writer and lecturer of singular force and clearness, holding a professorship of Natural History in the Royal School of Mines, with a curatorship in the Museum of Practical Geology. Among his more popular works are "Man's Place in Nature," "Lay Sermons," "Critiques and Addresses," "American Addresses," "Physiography," "Science and Culture," and "Lessons in Elementary Physiology." He died in Eastbourne, June 29, 1895.

SIR JOHN LUBBOCK, English naturalist and statesman, was born in London, April 20, 1834. He went to school at Eton, but his father needed his assistance in his banking house and he entered there at the age of fourteen, becoming a partner in 1856. In banking affairs he has introduced such improving innovations as the "Country Clearing" and the publication of the Clearing House returns. He was chosen Honorary Secretary to the Association of London Bankers, and, later, became the first President of the Institute of Bankers. He has also taken an active interest in many public affairs, has been a Member of Parliament and of various educational boards, President of the Royal Society and of the British Association for the Advancement of Science, and a member of many other learned bodies. Among his works may be mentioned "Prehistoric Times, as Illustrated by Ancient Remains and the Manners and Customs of Modern Savages," "The Origin of Civilization and the Primitive Condition of Man," "The Origin and Metamorphosis of Insects,'

'Ants, Bees and Wasps," "On the Senses, Instincts and Intelligences of Animals, with Special Reference to Insects," "On British Wild-flowers Considered in Relation to Insects," "Flowers, Fruits and Leaves." In the field of the moral and æsthetic he has written "The Pleasures of Life," "The Beauties of Nature," and "The Use of Life." In 1886 he delivered an address before the London Working Men's College on "Books and Reading." When it was published in 1887 as a chapter in his "Pleasures of Life," it had appended a list of the one hundred best books. This list stands high in the opinion of critics and is often quoted or referred to. He lives in London and in High Elms, Down, Kent.

MAURICE MAETERLINCK, dramatist and man of letters, was born in Flanders in 1854. All his school life was spent at a Jesuit college, where he was subject to severe monastic discipline, modified, however, in some degree by his being a day pupil. He began writing as a school-boy and persisted in this career contrary to the intentions of his parents, who wished him to be a barrister. He read French, German, and English, his enthusiasm in the latter field being for Shakespeare and other Elizabethan dramatists, for Carlyle and Emerson, Rossetti and Swinburne. He made a profound study of the mystical writers, his attention being drawn to them by the discovery in the public library of Brussels of the ancient and curious Flemish manuscripts of Ruysbroeck. His work is of the Symbolist order and he is looked upon as the leader of a movement known as "Young Belgium." He began publishing in 1890 by issuing a volume of verse entitled "Hot-House Blooms," and the two dramas, "The Blind," and "Princess Maleine." Other dramas followed: "The Seven Princesses," "Pelleas and Melisande," "Alladine and Palomides," "Aglavaine and Selysette," and "The Intruder." In 1897 appeared a volume of essays or reflective studies grouped around a central theme and called "The Treasure of the Humble." It was followed the next year by a similar work, "Wisdom and Destiny." In 1901 appeared a nature study: "The Life of the Bee."

ALEXANDER G. MCADIE, an American meteorologist, was born August 4, 1863, in New York city. He graduated from the College of the City of New York in 1881, then took a post-graduate course in Harvard, 1882–85. He was in the physical laboratory of the United States Signal Office from 1886–37, was appointed to the United States Signal Service, Washington, in 1891, where he remained four years, and then became local forecast official in New Orleans. In 1899 he accepted a similar position at San Francisco, where he now is. He has written extensively on meteorological subjects.

IRA REMSEN, Professor of Chemistry, and President, since June, 1901, of Johns Hopkins University, was born in New York, February 10, 1846. He graduated from the College of the City of New York in 1865, after which he studied medicine at the College of Physicians and Surgeons and, later, at the University of Göttingen, Germany, where he took the degree of Ph.D. From

1872 to 1876 he was Professor of Chemistry in Williams College, at which latter date he took the Chair of Chemistry in Johns Hopkins. In 1879 he founded, and has ever since edited, the "American Chemical Journal." He has written a number of text-books on chemistry. His home is in Baltimore, Md.

JOHN TIMBS, collector and writer of curious information, was born at Clerkenwell, England, August 17, 1801. He was educated at a private school at Hemel, Hempstead, after which he was apprenticed to a printer and druggist at Dorking. While here he began to write, and his first contributions appeared in the "Monthly Magazine" in 1820. He went to London to serve as amanuensis to Sir Richard Phillips, and at the same time began his contributions to London periodicals, but chiefly to the "Mirror of Literature," which he edited from 1827 to 1838. During 1839 and 1840 he edited the "Literary World," and was connected with the "Illustrated London News," as sub-editor under Dr. Charles Mackay from 1842 to 1858. He was the author of such works as "Curiosities of London"; "Anecdote Biography"; Clubs and Club Life in London"; "Historic Ninepins: A Book of Curiosities, where Old and Young May Read Strange Matters"; "A History of Wonderful Inventions"; "Knowledge for the People; or the Plain Why and Because"; "Lives of Wits and Humorists"; "Nooks and Corners of English Life"; "Past and Present"; "Popular Errors Explained and Illustrated"; "Things Not Generally Known, Familiarly Explained"; "Walks and Talks about London"; "Wonderful Inventions, from the Mariner's Compass to the Electric Telegraph." These are but a few of the more than one hundred and fifty titles of his books, consisting of compilations of interesting facts gathered from every conceivable quarter and relating to the most varied subjects. He was elected Fellow of the Society of Antiquarians in 1854. He died in London March 6, 1875.

JOHN TROWBRIDGE, an American physicist, was born in Boston, Mass., in 1843. He was educated at the Boston Latin School and in the scientific department of Harvard College. In 1879 he became Professor of Experimental Physics at Harvard and has won special distinction as an electrician. Among his works is "The New Physics."

JOHN TYNDALL, English physicist, was born in Leighlin-Bridge, County Carlow, Ireland, August 21, 1820. He began his original scientific researches in 1847, when teacher of physics in Queenwood College. In 1853 he was made professor in the Royal Institution, and three years later he and Prof. Huxley visited the Alps together, and wrote a work on the structure and nature of glaciers. His inquiries and experiments in connection with light, heat, sound, and electricity have all had practical results. He devoted the proceeds of a lecturing tour in this country to founding scholarships at Harvard and Columbia Universities for students devoting themselves to original research. Among his books are "Glaciers of the Alps," "Mountaineering," "Heat as a Mode of Motion," "On Radiation," "Hours of Exercise in the Alps,"

"Fragments of Science," "The Floating Matter of the Air," and volumes on Light, Sound, Electricity, and the forms of water. He died December 4, 1893.

ALFRED RUSSEL WALLACE, English naturalist and traveler, was born in Usk, Monmouthshire, Scotland, January 8, 1823, was educated as land surveyor and architect, but afterwards devoted himself entirely to natural history. He explored the Valley of the Amazon and Rio Negro, 1848–52, and traveled in the Malay Archipelago and Papua, 1854-62, publishing the results of his explorations. He also wrote "Contributions to the Theory of Natural Selection," "Miracles and Modern Spiritualism," "Geographical Distribution of Animals," "Tropical Nature," "Island Life," etc. His attention is occupied with natural history, social science, and scientific literature. He is President of the Land Nationalization Society.

CHARLES B. WARRING, American scientist, was born in Charlton, N. Y., January 15, 1825. He graduated from Union College in 1845; was principal of the Collegiate School in Poughkeepsie, N. Y., from 1857 to 1862, and in 1863 established the Military Institute at Poughkeepsie, which he conducted until 1891. Among his works are "The Mosaic Account of Creation, the Miracle of To-day"; "Genesis I. and Modern Science."